REPORT OF THE ADVISORY COMMITTEE ON ALTERNATIVES TO RICE STRAW BURNING

Advisory Committee Chair : Loyd Forrest
Advisory Committee Vice-Chair : Jack Williams
Advisory Committee Members : Illa Collin, Robert Holtzer, Dennis Lindberg, Larry Maben, John Merz, Gibbe Parsons and William Waite.

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EXECUTIVE SUMMARY

This is the second Biennual Report by the Alternatives Committee; the first was published in final during December 1995. This report is a revision of the first report, with updated information reflecting changes in the available alternatives to rice straw burning. Since the first report in 1995:

- The cost of rice straw collection, processing, transporting and storage is one of the primary common obstacles to almost all end user businesses.
- Significantly greater efforts are being devoted to finding and commercializing rice straw uses by entrepreneurs, the rice industry, public agencies and environmentalists. This will lead to some of the proposed technologies being commercialized; but not in time to use most of the approximately 1.5 million tons of rice straw generated annually.
- A new commercial facility that will use 10,000 tons (3,333 acres) to 20,000 tons (6,667 acres) annually of rice straw to create pressed board, is near operation.
- A new law was passed providing a tax credit of $15/ton of California rice straw diverted from burning and purchased for commercial uses. The tax credit is available from 1997 until December 1, 2008. Tax credits can be carried forward for ten years. The aggregate amount of the tax credits available each year is $400,000. This represents the straw produced from approximately 9,000 acres, of approximately 515,000 acres planted.
- The Integrated Waste Management Board and CalTrans have contributed $30,000 towards construction of a Demonstration Sound Wall made from rice straw to be built in the City of Williams in the fall of 1997.
- The County of Colusa has contracted with an architectural firm to construct a 7,000 square foot straw bale day care center. The City of Williams has applied to the Community Development Block Grant program for grant funds to support this construction.
- Legislation passed supporting the use of rice straw in residential and building construction, allowing rice straw to be used in conforming to local building standards.

However, there is little change to the 1995 Committee Report findings. New and promising alternatives have surfaced and some of the previously reported alternatives have made technological progress. <u>*Yet six years after passage of the Rice Straw Burning Reduction Act, there is not a major commercial facility under construction or in operation that would use a significant percentage of the annually produced rice straw*</u>. The most promising technologies still need research, capital investment and feedstock collection subsidies to attract the user technology companies and the needed financing.

The recommendations proposed by the Advisory Committee are specific and short term; they are designed to help bridge the period between the scheduled rice straw burning phase-down and the establishment of viable options to rice straw burning. The Advisory Committee foresees three alternative roles for government agencies in reducing the time needed for new alternative technology uses to become operational:

(1) Accepting part of the commercialization risk through direct subsidies such as tax credits and/or loan guarantees;

(2) Subsidizing new rice straw applications through government procurement, demonstration, research, cost-sharing and other similar programs; and

(3) Providing regulatory relief and support for permitting proposed rice straw-using facilities and the use of end products.

Previously, the Committee projected that by the years 2000 - 2005, commercial alternatives can occur if there are end user facilities jointly supported by the key stakeholders. It is important to note, that the Committee found little change to its 1995 Report key finding: that the absence of such initiatives leaves the rice industry with limited off farm rice straw alternatives to rice straw burning.

The Committee adopted this revised report at its May 29, 1997 public meeting. In preparing this report the Committee referenced a number of specific companies and products. The Committee makes no endorsement of named products businesses in this *report. Nor does the Committee imply criticism of similar products or business which are not named.*

I. RICE STRAW BURNING REDUCTION ACT OF 1991

The Rice Straw Burning Reduction Act of 1991 (AB-1378) mandates a reduction in rice straw acreage burning by the year 2000 using the following schedule:

Year	Planted Acreage that can be burned
1992	90%
1993	80%
1994	70%
1995	60%
1996	50%
1997	38%
1998	25%
1999	25%

2000 and thereafter limits burning to no more than 25% of the planted acreage or 125,000 acres in the Sacramento Valley, whichever is lesser. However to burn any acreage after 1999 requires specific regulatory findings that economically and technically feasible alternatives to burning are not available, and that “...the county agricultural commissioner makes a finding that the existence of a pathogen during the growing season caused a significant, quantifiable reduction in yield”.

In addition, the Act created the Advisory Committee on Alternatives to Rice Straw Burning "to assist with the identification and implementation of alternatives to rice straw burning" and "develop a list of priority goals for the development of alternative uses of rice straw for the purpose of developing feasible and cost-effective alternatives to rice straw burning". As required in the Act, the Advisory Committee was jointly appointed by the California Air Resources Board (CARB) and the Department of Food and Agriculture (CDFA) and includes ten members representing the rice industry, health and medical professions, elected County Supervisors (or their representatives) from three of the rice growing counties, including one representing the Sacramento Valley Basin Air Pollution Control Council, environmentalists and an end-user business representative.

During 1996-97, the Advisory Committee met periodically in Sacramento or in one of the Sacramento Valley rice growing communities. The Committee pursued identifying alternatives to burning rice straw, the commercial status of each alternative and the existing volumes of rice straw being used by each alternative. The Advisory Committee, along with the CARB and the CDFA, made extensive outreach efforts to involve the rice growing industry, end-use entrepreneurs, researchers and rice growing experts, environmentalists, various state, local and federal government agencies with interests in the rice growing area and members of the general public with interest or expertise. This report is a joint product of the Advisory Committee and its subcommittees, with input from the above referenced stakeholders. It is encouraging that the above entities have responded well in sharing their knowledge and expertise with the Committee, resulting in this report.

With the help of the above parties, the Advisory Committee identified numerous alternatives and evaluated:

- The existing uses of each alternative including the status of commercialization.

- Projected uses through the year 2000.

- Projected uses by the year 2000 if recommendations contained in this report are implemented.

Based on this approach, the Advisory Committee compiled recommendations to encourage development of the most promising alternatives that should be considered by the State and local governments, the rice industry, environmentalists, potential end-user businesses and other stakeholders to expand the future uses and non-burn disposal of rice straw.

II. SUMMARY OF PRIORITY GOALS, FINDINGS AND RECOMMENDATIONS

A. PRIORITY GOALS

That the state and local governments, rice industry, environmentalists, and the end-user businesses work together to create off farm rice straw alternatives to burning that will use 25% of the rice straw by the year 2000 and 50% or more by the year 2003.

B. FINDINGS

1. The off farm alternative uses of rice straw are minimal today, with approximately 0.6% or 8800 tons used in off farm alternatives, of the estimated 1.5 million tons of rice straw generated annually.

2. Under a “business as usual” approach, the off farm alternative rice straw uses are likely to still be minimal (estimated 2.1%) by the year 2000.

3. None of the interested parties to the rice straw burning problem, the rice industry, government agencies, environmentalists, or potential rice straw end-user businesses, can unilaterally develop commercial facilities that use large volumes of rice straw. In the opinion of the Advisory Committee, the only solution that will have any significant impact will be to create joint public/private initiatives to invest in the first commercial facilities. If significant joint efforts aren’t made and business as usual prevails, then the year 2000 and beyond will arrive without significant alternatives being developed.

4. Implementing the Advisory Committee recommendations, an estimated 25% of the annual rice straw could be used by off farm alternatives by the year 2000.

5. Given the lack of progress to date in developing alternative uses of rice straw, the rice industry is likely to experience serious economic losses if the burning phase-down proceeds on schedule. More time is needed for (a) development of the off farm market alternatives and (b) research on the application and impacts of the on farm alternatives.

C. RECOMMENDATIONS

The recommendations proposed by the Advisory Committee are specific and short term; they are designed to help bridge the period between the scheduled rice straw burning phase-down and the establishment of viable options to rice straw burning. The Advisory Committee foresees three alternative roles for government agencies in reducing the time needed for new alternative technology uses to become operational:

a. Accepting part of the commercialization risk through direct subsidies such as tax credits and/or loan guarantees;

b. Subsidizing new rice straw applications through government procurement, demonstration, research, cost-sharing and other similar programs; and

c. Providing regulatory relief and support for permitting proposed rice straw-using facilities and the use of end products.

Following are the committee's recommendations:

1. *Private financial institutions are usually willing to finance between 50 to 60 percent of promising commercial projects for new technology applications if sound projects are developed. Developer-owners typically provide another 10 to 20 percent of the equity capital. To spread new technology investment risk among the beneficiaries of commercializing the new rice straw technologies (i.e., the developers, the investment banks and the public), legislation should be pursued to provide up to 30 percent loan guarantees for the first two commercial facilities of each new technology application in the Sacramento Valley. Some potential state agency funding sources for the loan guarantees are the (a) California Pollution Finance Control Authority and (b) the Alternative Energy Financing Authority. Estimates of the proposed loan guarantees are $10-30 million of obligations by state government. If the projects are successful, funding is not required from the state. As evidenced by the extensive use of government loan guarantees for housing, this approach is the least expensive government subsidy for administering, and keeps the private lenders primarily at risk for all of the initial debt funding.*

2. *The Rice Straw Tax Credit should be amended to allow broader support for the development of alternative use technologies. The annual aggregate cap of $400,000 currently to 9,000 acres out of 515,000 acres planted in 1996/97.*

3. *State, federal and local governments should encourage the use of rice straw ethanol for energy uses by: devoting research funds to improving the new technologies market efficiencies, conducting demonstrations projects to educate the potential consumers and end-user businesses of the uses of rice straw as an energy source, and providing regulatory support for environmental analyses that support the development of these technologies in the market place and give credit for their environmental benefits to California.*

4. *CARB, CDFA, California Energy Commission, the Rice Research Board, and other funding organizations with related interests, should undertake jointly funded research and development efforts to improve the economics of collection, transportation and storage of rice straw for diversion to off farm alternative market uses.*

5. *CARB, the CDFA, the Department of Consumer Affairs, the California Energy Commission, environmentalists, the rice industry, and Sacramento Valley cities and counties should continue to support appropriate construction standards for rice straw building construction. In addition, jointly funded demonstration projects are needed to educate the public, regulatory agencies and potential commercial market users on rice straw in building construction.*

6. *State government, the University of California and the rice industry should promote and facilitate research in crop rotation systems, including new crops, to provide additional straw disposal approaches as a means to increase the effectiveness of rice straw incorporation.*

7. *State government, the University of California and the rice industry should promote and facilitate continued research on methodology and soil/crop impacts of on farm disposal and removal of rice straw.*

8. *Consider amendments to AB-1378 which will allow permit trading under the conditional burn section.*

9. *State, federal and local governments, and the rice industry should encourage the use of rice straw for environmental mitigation, educate the potential consumers and end-user businesses of the uses of rice straw as a raw material, and provide regulatory support for environmental analyses that support the development of this application in the market place and give credit for the resulting environmental benefits to California.*

    a. *The High Sierra Resource Conservation Development Council and the Farm Services Agency for Placer County worked jointly on a project to promote the* *use of rice straw for erosion control at construction sites. The committee strongly recommends that these agencies and growers continue to work together towards the formation of a cooperative or similar effort to stabilize prices and meet demand.*

b. *Much of the environmental mitigation work on roads and fire rehabilitation is under the direct control of state, local and federal agencies. Therefore CARB and the CDFA should assess the need and identify how to target the governmental agencies involved in planning and implementing environmental mitigation, to optimize rice straw use in their rehabilitation efforts.*

c. *The Committee recommends that funds be budgeted in one or more state agencies, for example the California Department of Forestry and Fire Protection (CDF), to make straw available on an on-going basis. Such agency could contract for this service. If properly stored after cutting and baling, the straw could be transported on demand for erosion control or fire rehabilitation conducted by that agency.*

III. CURRENT AND FUTURE RICE STRAW ALTERNATIVES

In addition to open-field burning, two categories of rice straw alternatives were identified by the Advisory Committee: (1) Off farm alternatives; and (2) Infield-disposal alternatives. Off farm alternatives include diversion of rice straw to energy production; construction and manufacturing uses; environmental mitigation; and livestock feed. Infield-disposal alternatives encompass cultural practices of rice straw incorporation in the growers' fields.

Of the estimated 1.5 million tons from 514,720 acres of rice straw generated during the 96-97 season, approximately 883,794 tons from 294,598 acres (57 percent of production) were disposed of using on farm methods. Off farm disposal of rice straw was 0.6% of the total 1996-97 rice straw produced. The Advisory Committee estimates that approximately 8,800 tons or 2,933 acres of rice straw was diverted to environmental mitigation, erosion control and livestock utilization. Without major changes in the market place, the Advisory Committee projects the current low level of off farm rice straw disposal will continue with little change during the next three years.

Using three tons of rice straw/acre, Table I reflects the Advisory Committee's estimates of rice straw currently used and projected to be used by the year 2000 under a business as usual scenario.

Table I
Estimates of current and projected off farm, rice straw disposal/year.

Alternative Uses	Column 1 Estimated Current Use	Column 2 Projected Use Year 2000
Energy Alternatives:		
Gasification	0	0
Anaerobic Digestion	0	0
Direct Combustion	0	0
Ethanol, Chemicals	0	**
Manufacturing/Constructi on		
Pulp Mills/Paper	0	**
Fiberboard	0	21,000 tons/7,000 acres
Composites	0	0
Bricks	0	0
Bale Construction	*	1,000 tons/333 acres
Sound Walls	0	500 tons/167 acres
Environmental Mitigation	7,450 tons/2483 acres	7,450 tons/2,483 acres
Livestock Utilization	1,350 tons/450acres	2,500 tons/833 acres
Off Farm Total % 1996-97 production	8,800 tons/2,933 acres 0.6%	32,450 tons/10,816 acres 2.1%

* Occasional, but minimal volumes of rice straw used by these alternatives.

** It is possible but uncertain that the ARBOKEM, SEPCO or the Gridley projects will be constructed by the years 1999-2000.

Column 1 of Table I shows that very little rice straw is being diverted to off farm alternative uses. Column 2 projects the volumes of rice straw that will be used by off farm alternatives during the year 2000, given projected market conditions. The year 2000 usage estimates are 32,450 tons (10,816 acres) per year or 2.1 percent of projected rice straw production. In this scenario, rice growers will be forced to rely heavily on field incorporation of rice straw to comply with the legislative required burning phase-down. For reasons discussed later in the report, this option is problematic.
Table II summarizes the estimates of current and projected rice straw disposal given the timetable of the phase-down and the status of the development of off farm alternatives.

Table II.
Current and projected rice straw uses
without increased development of off farm alternatives (per year)

Alternative	**Col. 1** **Current Disposal** **(tons/acre)**	**Col. 2** **Estimated Disposal by Year 2000 (phase-down)** **(tons/acre)**
Burning %96-97 production	633,966 tons/ 211,322 acres **41%**	386,000 tons/ 128,680 acres **25%**
Off Farm %96-97 production	8800 tons/2933 acres **0.6%**	32,450 tons/10,816 acres **2.1%**
On farm %96-97 production	883,794 tons/ 294,598 acres **57.2%**	1,125,672 tons/ 375,224 acres **72.9%**
Total %96-97 production	514,720 acres **100%**	514,720 acres **100%**

* Assumes the maximum that is allowed under the existing statutes; 25% of the planted acres are burned.

* Sacramento Valley rice acreage; data from the California Air Resources Board.

During the 96-97 crop year, farmers incorporated approximately 57 percent of total planted acres. However, as shown in Column 2 of Table II, if off farm alternatives are not developed to use the straw that can't be burned, rice farmers will be forced to incorporate an estimated 73 percent of production by the year 2000 to comply with the statutory rice straw burning phase-down requirements. This assumes maximum use of the 25% burning for disease control, under AB 1378, the 1991 phase-down legislation. Incorporation of rice straw back into the field has not been adequately researched or tested for adverse (or positive) soil/crop impacts. However, available research and experience suggest that incorporation rates this high could impose an extraordinary financial and operational burden on rice farmers in the region.

There is a still a large gap between the time frame for the required burning phase-down and the time needed for the establishment of significant off farm alternatives. Although the Advisory Committee found a number of committed and energetic entrepreneurs with potentially viable rice straw technologies, they are relatively new in the market place. It is uncertain that alternatives with the potential for significant rice straw uses will be fully operational by the year 2000.

Making greater uses of the off farm alternatives to rice straw burning will require an extensive cooperative approach among state and local government agencies, the rice industry, environmentalists, individual entrepreneurs and businesses that could potentially use rice straw as a raw material. None of these entities can unilaterally effectively address creating market alternatives for rice straw disposal. Collaborative efforts are needed to spread the financial and technological risk of creating new industry uses for rice straw. Table III shows the estimated rice straw that could potentially be diverted by the year 2000 if the Advisory Committee's recommendations are implemented.

Table III
Estimates of best case off farm, rice straw uses by the year 2000, with implementation of Advisory Committee recommendations.

Alternatives	**Projected Use Year 2000**
Energy Alternatives:	
Gasification	0
Anaerobic Digestion	0
Direct Combustion	0
Ethanol, Chemicals	348,000 tons/116,000 acres *
Manufacturing/Construction	
Pulp Mills/Paper	0
Fiberboard	21,000 tons/7,000 acres
Composites	0
Bricks	0
Bale Construction	3,000 tons/1,000 acres
Sound Walls	2,400 tons/800 acres
Environmental Mitigation	15,000 tons/5,000 acres
Livestock Utilization	2,500 tons/833 acres
Off Farm Total % 1996-97 production	391,900 tons/130,633 acres 25.4%

* Assumes public subsidy of up to 30% loan guarantees for the first two plants.

With an aggressive government agency effort and a collaborative approach with the rice growers and potential new industry users, Table III shows that it may be possible by the year 2000 to dispose of an additional 359,450 tons (119,117 acres) of rice straw beyond the business as usual scenario. Thus, with implementation of the Committee's recommendations, the total rice straw that could potentially be processed by off farm alternatives by the year 2000 is estimated at 391,900 tons/130,633 acres per year, or 25.4 percent of the 1996-97 production.

These estimates represent a best-case scenario for off farm diversion by the year 2000. If off farm alternatives can divert 25.4 percent of rice straw production by 2000, then rice farmers would still have to incorporate 49.6 percent of the rice straw to comply with the burning phase-down (assuming 25% could be burned under the existing laws). This is in sharp contrast to the 72.9 percent minimum that would need to be incorporated (or burned) if there is not substantial growth of off farm alternatives for disposal of rice straw.

Recognizing that development of off farm alternatives has been slower than expected when the phase-down legislation was passed, and that the successful implementation of the Advisory Committee's recommendations is uncertain, the Advisory Committee recommends changing the legislatively mandated phase-down schedule of rice straw burning, to allow more time for alternatives to be developed by the interested parties, i.e., government, rice industry, environmentalists, and end-user businesses. The Advisory Committee feels that the additional time is needed for the commercial alternatives to be implemented.

BACKGROUND

The Process of Rice Cultivation in California

California is the second largest producer of rice in the nation and the largest producer of medium-grain rice. Of all the agricultural crops grown in California, rice is ranked 18th in harvested value (California Agricultural Directory [1994]). Ninety-five percent of California rice is in the Sacramento Valley where rice is the most widely planted crop. During the last fifteen years, state wide rice plantings have averaged approximately 406,000 acres of rice per year (ARB [1995]). The leading counties for rice production in California are all found in the Sacramento Valley, including Colusa, Butte, Sutter, Glenn, Yolo, Placer, Sacramento, Tehama and Yuba counties.

In the Sacramento Valley, rice planting takes place from April 15 to May 31, with most fields planted from May 1 to May 20. Harvesting starts September 1 and runs to October 31 with a few late fields harvested in November. Average yields for the last two to three years have been approximately 84 cwt/acre (cwt is U.S. short hundredweight which equals 100 pounds). Recoverable and/or burnable rice straw production is typically estimated at 3 tons/acre, and this is the conversion used throughout this report. However, actual above ground straw production is closer to 3.5 tons/acre.

After the rice is harvested in the fall, the straw must be cleared in preparation for future crops. Burning the rice straw has been the standard method for clearing the fields and disposing of the straw. Burning is relatively cheap and easy and in addition, it helps control rice diseases such as stem rot that can reduce the yields of future crops.

Developments in both the annual Farm Bills and the Japanese market will be very important in determining the ability of the California rice industry to remain profitable and the ability of the industry to absorb increases in straw-management costs due to the burning phase down.

Criteria for Assessing the Potential of Off farm Alternatives

To identify those off farm alternatives that offer the most potential for the disposal or diversion of rice straw, the Advisory Committee and the respective subcommittees evaluated the technological process and constraints of each alternative; the economic feasibility of each alternative; and the commercial development status of each alternative.

C First, the technological process and constraints of each alternative were considered. The physical and chemical characteristics of rice straw limit the types of technologies that can be used successfully to process rice straw. The primary structural components of plants, such as cereal grains or woody plants, are cellulose, hemicelluloses, and lignins. For cereal-grain straw and softwoods, cellulose comprises about 30 to 45% of plant mass, hemicellulose 15 to 28%, and lignins, 7 to 33% (Bainbridge [1992]). Relative amounts of these substances vary among different plants. Non-wood fibrous plant material also contains varying amounts of silica. The silica entering the production process consists of silica from plant cells and silica compounds from the soil that sticks to the outer surface of the plants. Rice straw contains a relatively large amount of silica compared to other grass species; up to 18%, averaging about 14% for color varieties (Fadel, 1995). Additionally, the elemental composition of rice straw consists of hydrogen (5.5%), carbon (36%), oxygen (38%), nitrogen (0.6%), sulfur (0.1%), potassium (1.5%), phosphorus (0.1%), and ash (17.8%). These values are similar to those of wheat straw except for greater ash (wheat ash is about 7%) (Walker [1981]).

C The chemical and physical composition of rice straw signals potential use in a variety of technologies. For example, the high carbon content could be an asset in energy conversion or soil amendment, etc. Conversely, the composition of the straw, particularly the high silica content, could constrain the type of technological processes that can be efficiently adapted to rice straw. The presence of silica in non-wood fibrous plant materials contributes to the difficulty of obtaining a satisfactory and competitive product. This is particularly true for rice straw (Atchison [1988] and Zeronian et al. [1981]). The abrasive nature of the rice straw creates high wear and maintenance for processing equipment, resulting in processing cost increases over that of more desirable materials (Dobie and Mosley [1981]). Handling and cleaning of rice straw prior to processing removes a high percentage of silica from the outer surfaces and eliminates part of the organic silica contained within the straw. However, the high internal silica content of rice straw makes this material less attractive compared to other cereal straws (Kopfman and Hudeczek [1988]). For each of the technologies considered by the Advisory Committee, the adaptability of rice straw to the technological process was the first consideration.

C The second aspect that the Advisory Committee considered when evaluating the potential of each alternative was the economic feasibility of the alternative. The ultimate capacity of an alternative to divert rice straw depends both on the market demand for the final commodity produced by the alternative and on the attractiveness of rice straw as an input in the production process. Demand for the final commodity will depend on market forces and government regulation. The attractiveness of rice straw as an input in the production process will depend on the suitability of rice straw to the process and the availability of superior or less expensive substitutes. The Advisory Committee attempted to evaluate both final-commodity demand and rice straw input demand in order to assess the economic viability of the alternative.

C The third aspect that the Advisory Committee considered when evaluating the potential of each alternative was the status of commercial development of the alternative. Commercialization of new technologies typically goes through five stages: 1) concept development; 2) laboratory bench or empirical testing; 3) prototype facility for evaluating engineering processes and throughput production processes; 4) the first commercial plant; and then 5) wide-spread multiple facility commercialization. The level of commercial development reflects the private market's assessment of the technological and economic feasibility of the alternative. In addition, the level of commercialization also reflects the time element involved in the establishment of any of the alternatives. Commercialization is a process that necessarily dictates a certain time frame for the successful completion of each stage in the process. For each alternative considered by the Advisory Committee, the level of commercial development served as a strong indicator of the viability of the alternative and of the time period necessary for the establishment of the alternative.

The recommendations concerning the technical, financial, or institutional programs supporting the establishment of viable alternatives depended on an evaluation of the technological process and constraints, economic feasibility and level of commercial development of each of the alternatives. In addition, the Advisory Committee was very cognizant of the time element involved in the implementation of the rice-burning phase-down. By the year 2000 rice straw burning may be limited in the Sacramento Valley (75 -100% of the rice straw planted can not be burned under existing statutes) and any alternative, no matter how promising, that cannot begin processing or disposing of rice straw within the next four years is not a viable alternative for the farmers of the Sacramento Valley.

SUBCOMMITTEE REPORTS ON ALTERNATIVES

The Advisory Committee identified five categories of alternatives to rice straw burning:

Off Farm Alternatives:

(1) Energy Conversion,
(2) Manufacturing and Construction,
(3) Environmental Mitigation,
(4) Livestock Feed.

On farm alternatives:

(5) Cultural Practices

A subcommittee was created to conduct the detailed examination of the alternatives. The report of each subcommittee is presented in the sections that follow. Each subcommittee report examines the technological process and constraints of the alternatives under consideration; the economic feasibility of the alternatives; the commercial development of the alternatives, and the potential capacity of the alternatives to divert rice straw. Each subcommittee also made recommendations to aid in the establishment of the most promising alternatives under consideration. Examination of the status of rice straw marketing in the Sacramento Valley is considered at the end of the section on off farm alternatives.

I. OFF FARM ALTERNATIVES

A. REPORT OF THE SUBCOMMITTEE ON ENERGY ALTERNATIVES

The high energy content of rice straw, up to 8,000 Btu per pound, makes energy conversion an attractive option for rice straw diversion. There are a number of technical options for energy production from rice straw including: transportation fuels and industrial chemicals, direct combustion, ethanol production and anaerobic digestion. Each of these technologies produces a different energy commodity and each uses the rice straw input in a different manner. For these reasons, the market and production constraints inherent to each of the energy alternatives are very different. The technological process and constraints, economic feasibility, extent of commercial development, and potential capacity of each type of energy alternative is examined below.

Transportation Fuels and Industrial Chemicals

Technical Process and Constraints

Since the Committee's 1995 report, a number of companies have appeared with technologies that convert biomass materials, such as rice straw, into a number of industrial chemicals, including transportation fuels. One such company, Biometrics' Biofine has a proprietary technology that degrades cellulose to produce levulinic acid. The transportation fuel methyltetrahydrofuran (MTHF) and other chemicals are obtained by further conversion of the levulinic acid and other chemical reactions.

MTHF is a fuel additive and can be used as a component in an alternative fuel formulation. It can be blended with either gasoline or ethanol. In addition, it would fulfill the new EPA regulations for a 2.7% content of oxygen in base gasoline formulation, without unnecessarily increasing the octane value of the product.

The chemicals that can be produced from feedstock include: diphenolic acid, succinic acid, and tetrahydrofuran. Diphenolic acid is used as a component in protective coatings and decorative finishes. In addition, it can be used in the production of polycarbonate and epoxy resins. Succinic acid can be used as a food additive and tetrahydrofuran is used primarily for production of polymers and resin. All of these chemicals are widely used and can be produced more cheaply for yeast or low cost cellulosic feedstocks.

Economic Feasibility

Although Biometrics has not used rice straw in manufacturing MTHF or the other chemicals, the company believes that the technology can be modified to utilize rice straw as a feed stock.

Commercial Development

A pilot plant is under construction in New York using local biomass as feedstock. Results of the pilot plant will determine the future commercialization schedule.

<u>Direct Combustion</u>

Technological Process and Constraints

Direct-combustion alternatives considered by the Energy Subcommittee include burning rice straw in biomass power plants for electricity production both through the gasification and direct combustion of rice straw.

Gasification of Rice Straw

Primenergy Inc. has developed a biomass energy conversion system which gasifies agricultural waste creating a fuel to generate heat, steam, and/or electricity. A main component of this system is a reactor which gasifies the feedstock, creating a natural gas substitute fuel. The company has employed this technology at over ten plants around the world. The oldest facility has been in operation since 1983. However, these plants primarily use rice husks or other agricultural wastes besides rice straw, as their feedstock.

The company has tested 47 tons of rice straw at its test facility in Tulsa Oklahoma. The tests were successful. However, rice straw is a more expensive fuel to use since it must be chopped up prior to use. In addition the rice straw appears to require a custom feeding process to avoid "building" or clogging of the straw.

Another company, Clean Custom Fuels, Inc. also has a technology which can produce gas or liquid distillate from biomass or other cellulose raw material feedstocks. The company has tested its technology successfully at two demonstration plants using municipal solid waste. The company has not run any tests utilizing rice straw but believes the technology can be adapted to use rice straw and hope to test it in the future.

Commercial Development

This technology is proven and operating at a number of facilities in the US, Central America, Australia and Malaysia. The technology appears to be very adaptable to rice straw. Further research is needed on economical, processing and feeding the rice straw into the gassifier to compete with other biomass material such as rice hulls, green waste and sewage sludge.

The physical and chemical characteristics of rice straw make it a difficult fuel to process. Although rice straw has up to 8,000 Btu/lb, certain chemical and physical characteristics make it unusable for direct combustion in the 51 remaining biomass power plants constructed and operated in California. The following factors have caused all of the power plants near the rice-growing areas to eliminate the use of rice straw as a biomass feedstock.

1. The alkalinity (particularly the potassium and chlorides) of the rice straw has created serious and costly slagging problems in the biomass power plant boilers. Large accumulations occur on the boiler walls, creating unscheduled downtime for removing the slagging. Proposed solutions to the alkalinity problem suggested for research by the University of California at Davis Agriculture Engineering Department are to leave straw in the field to overwater or to wash the straw to reduce its alkalinity before combustion.

2. The high silica content of rice straw (averaging 15-19%) results in high ash content. This ash must be disposed of and reduces the energy efficiency of the biomass boilers. Where ash content with most competitive biomass feedstocks range from 0.5-2%, the silica content in rice straw can drive ash content to 15% or higher. Another concern, referenced by Dr. Robert Holtzer, formerly of the Office of Environmental Health Hazard Assessment of the California Environmental Protection Agency, is the possible production of crystalline silica, a potentially carcinogenic material, from combustion of rice straw. Dr. Holtzer noted that Wadham Energy experienced this problem with rice-hull combustion and that the California Department of Toxic Substances Control required handling the ash as a hazardous waste. Wadham Energy subsequently modified their combustion conditions to reduce production of crystalline silica.

Economic Feasibility

In addition to the technological constraints to direct combustion of rice straw, at least two economic conditions severely limit the viability of this option. The first is the recent decline in demand for biomass fuels. This observation is evidenced by recent reductions in biomass power plant capacity in California. Prior to 1994, at least fifteen biomass plants in California were either closed, converted to gas, or curtailed. During 1995, another six biomass plants contracts in California were bought out, with three more curtailment agreement contracts signed in 1996. As of April 1997, there were 29 operating biomass power plants in California. However, some of the signed curtailment agreements require the biomass power plants to come back on line in year 11 of the power sales contracts.

The importance of the biomass power plant closures and curtailments in that the volume of agriculture wastes disposed of through direct combustion, significantly decreased during the last few years.

The second economic condition that limits the viability of direct combustion of rice straw is the large supply of biomass for direct combustion. Not only do wheat straw, orchard prunings and other more suitable agricultural byproducts compete with rice straw in the biomass-combustion market, but biomass supply from other sources such as urban woodwaste and fire-hazard reduction programs in California's timber regions are increasingly competing in the biomass market.

Moss et al. (1993) in the "Foster Report," present calculations on biomass energy production indication that "under almost every single forecasting scenario netback prices for agricultural residues are negative" (page A-8). Even if the other economic hurdles are surpassed, the biomass energy alternative for rice straw disposal will probably not reduce straw management costs for rice farmers in the short to medium term.

Commercial Development

Currently all direct-combustion commercial plants in California use other sources of fuel. It has been reported (Moss et al. [1993]) that one biomass generator plant, Wadham Energy, experimented with burning rice straw in its commercial operation. In 1991, about five percent of Wadham's fuel input was met by rice straw. It no longer uses rice straw due to technical difficulties.

Direct combustion of rice straw is back to the laboratory-testing stage. Future exploitation of rice straw in direct combustion is highly dependent on the development of new techniques to mitigate the technological difficulties associated with the high silica content and alkalinity of the rice straw. Some research is taking place in this direction. The Agricultural Engineering Department of the University of California at Davis is currently researching the potential for reducing the alkalinity of rice straw to prevent slagging problems in direct combustion.

Potential for Rice Straw Diversion to Direct Combustion Uses

<u>Ethanol Production</u>

Technological Process and Constraints

The Energy Subcommittee researched three fuel-ethanol production technologies: steam explosion, acid hydrolysis and enzymatic hydrolysis. The three technical approaches use parallel processes for converting rice straw to ethanol. In each, rice straw is transported to a conversion facility, pulverized, mixed in a liquid slurry, and subjected to a process wherein the complex cellulose molecules are broken down into simple sugars. The resultant sugar-rich liquid is then subject to fermentation, and the fermentation products are distilled to ethanol. Secondary products such as lignin, silica and, in the case of acid hydrolysis, gypsum, are drawn off at various points in the process.

The steam explosion, acid and enzymatic hydrolysis technologies differ only in the means by which the complex cellulose molecules are broken down to fermentable sugars. The currently proposed acid hydrolysis technology uses either sulfuric or nitric acid, while the enzymatic hydrolysis technology uses a combination of steam and enzymes produced from genetically-engineered fungi or bacteria. The enzymatic hydrolysis process offers an alternative that reduces the use of acids to break down cellulose and complex sugars into fermentable simple sugars. In the enzymatic process, rice straw is pre-treated to separate cellulose and hemicellulose components. The hemicellulose is then broken down to simple sugars using a dilute acid mixture, while the cellulose is broken down using enzymes. The enzymatic process offers the potential for more efficient conversion of cellulose to sugars, thereby offering potentially higher overall yields of ethanol for a given amount of rice straw.

Economic Feasibility

Both the acid-hydrolysis technology and the enzymatic technology depend on relatively high ethanol prices for commercial feasibility. It is estimated that ethanol production costs must be between 70 cents and one dollar per gallon to be competitive at current market prices, without government tax subsidies. Current projections suggest a growing market for ethanol. Nationally, fuel ethanol use grew from a negligible amount in 1977, to approximately 1.4 billion gallons per year in 1995. In California, fuel ethanol consumption is approximately 50 million gallons. The deficit, approximately 45 million gallons, is imported primarily from the 20 Midwest corn to ethanol producing states.

Ethanol demand and ethanol-producer prices are currently dependent on government subsidies and environmental standards and controls. The U.S. Environmental Protection Agency permits ethanol to be included as a component of oxygenated gasoline that is now required in large urban areas in the wintertime by the 1990 Clean Air Act Amendments. As a component of “gasohol” or as an additive, ethanol end-users can receive an income-tax credit of 54 cents per gallon. As a component in gasoline blends, blenders can receive a sliding-scale excise tax exemption beginning at 5.4 cents per gallon of blend. The 1992 National Energy Policy Act grants an additional 10 cents per gallon income tax credit to facilities producing less than 30 million gallons per year. All of these tax subsidies are set to expire in 2001, though Congress has historically renewed them on a regular basis (see Moss et al [1993] for a more detailed description and analysis of government subsidies and environmental programs). As a result of this potential expiration, none of the proposed biomass to ethanol projects can depend upon a government tax credit for financing. In effect, to be financed, a proposed rice straw to ethanol facility must be economical without the proposed blenders tax credit since amortizing the debt will require a ten to sixteen year loan. The lenders will not assume a tax credit in evaluating the economic viability of a proposed ethanol project.

Commercial Development - Acid Hydrolysis

There is one pilot acid hydrolysis plant for conversion of rice straw currently operating in California, that has successfully processed many varieties of California rice straw. Arkenol, Inc. (Ark Energy) is permitted to build an acid hydrolysis and a gas turbine power plant in Rio Linda, California. The Sacramento Ethanol and power Cogeneration Project (SEPCO) will generate electricity using natural gas in one process and convert rice straw to ethanol in another process. Waste heat, from the natural gas turbine would provide thermal input to the ethanol production process.

The SEPCO project would process approximately 100,000 tons of rice straw per year, which represents approximately 7% of the rice straw produced in the Sacramento Valley in an average rice production year. If it proceeds on its recently revised schedule, the SEPCO project will be constructed in time to process rice straw from the 1999 rice crop, however, funding is still being negotiated and there is a degree of uncertainty as to whether or not this schedule will be kept.

Commercial Development - Enzymatic Hydrolysis

The enzymatic hydrolysis has received extensive research support from the National Renewable Energy Laboratory (NREL) of the Department of Energy. The current ethanol production base is corn, and the focus of NREL research has been on corn-to-ethanol technologies. In August 1994, NREL began operation of an enzymatic hydrolysis pilot plant at its facility in Golden, Colorado. The plant is capable of processing one ton of biomass per day. During the last two years, the NREL facility has extensively researched and processed California rice straw at its facilities in Colorado. Engineering scale production runs of rice straw has successfully proven the technology feasibility of producing ethanol from California rice straw.

To pursue the development of biomass to ethanol production technology, NREL worked with several different companies in the private sector, including Weyerhaeuser, AMOCO, Arkenol, BCI, Delta T and Hawaiian Electric. One of the private ethanol companies will likely become the lead equity player for the proposed ethanol production facility in Gridley. The proposed facility could be capable of processing between 100,000 and 250,000 tons of rice straw per year. The City of Gridley project has completed the feasibility study and is negotiating with alternative equity owners for a private developer to move the project into the commercial stage.

Potential for Rice Straw Diversion to Ethanol Production

In contrast with the direct combustion options discussed above, the Energy Subcommittee determined that the technologies for converting rice straw to liquid ethanol fuel offered a feasible and potentially significant opportunity for diversion of rice straw. If the best case projections of SEPCO and the City of Gridley are fulfilled, ethanol fuel conversion of rice straw could divert up to 40% of the average yearly production of rice straw. The basis for this is that projection is the following:

- Millions of dollars have been spent by both SEPCO and the City of Gridley in project development.
- Both project developers have identified and conducted facility siting evaluations.
- Both SEPCO and Gridley have completed feasibility studies.
- SEPCO has completed all of its permitting, engineering drawings and obtained its vendor guarantees.
- Gridley has over $5 million in the bank to complete its project development and get to financing and construction.

Although other technologies may be equally viable, limited time is available between now and the year 2000 for large capital investment projects to conduct feasibility studies, develop business plans, identify and do site evaluations, obtain the land, develop an Environmental Impact Report, obtain the variety of permits required, obtain vendor guarantees, develop preliminary and final engineering drawings, let construction and procurement contracts, obtain vendor guarantees, and other similar requirements before financing can be obtained and construction started.

For large projects that would use significant volumes of rice straw, the only two that may be on line by the year 2000 are the proposed SEPCO and Gridley projects.

However, neither of the two plants is operating and there remains a degree of uncertainty regarding both the financing and the start-up date for either plant. Under current projections, the SEPCO plant potentially could be in operation during 1999, and the Gridley project during the year 2000.

Anaerobic Digestion

Technological Process and Constraints

Anaerobic digestion is a complex fermentation process, performed in the absence of oxygen, in which organic waste is converted to methane and carbon dioxide gases and other stable end-products. Some types of biomass such as wood and straw must go through a pre-treatment stage before fermentation can occur. For these types of biomass, anaerobic digestion is a three-stage process. In the first stage (the pre-treatment stage), the complex organic compounds are broken into soluble components that can be used by the enzyme-forming bacteria. In the second stage, these soluble materials are oxidized to low-molecular-weight organic acids. In the third stage, methanogenesis (methane fermentation) occurs. (For a more detailed description of the anaerobic digestion process see Kaybanian et al. [1991] or WRBEP [1988]).

The gas produced from the anaerobic digestion of an organic material is called “biogas," and consists primarily of methane and carbon dioxide with small amounts of other gases including hydrogen sulfide, hydrogen, nitrogen and low-molecular-weight hydrocarbons. Biogas is combustible and yields a thermal energy value of about 550 Btu/ft3.

Many feedstocks including manure, kelp and wheat straw have been used in anaerobic digestion. The amenability of a feedstock to anaerobic digestion depends on the amount and type of pre-treatment needed to breakdown the complex cellulose in the material. Municipal solid waste has a very good potential as a feedstock because it requires very little pre-treatment. Agricultural residues, including rice straw require fairly extensive pre-treatment, and in the case of all agricultural residues, manure is usually added to the residue to provide nutrients and inoculum.

Economic Feasibility

A detailed study of the feasibility of anaerobic digestion of agricultural crop residues, including rice straw, was conducted in 1981 by Ashare and Buivid. The objective of their study was to provide cost estimates for the pre-treatment and digestion of crop residues to fuel gas and to determine the economic feasibility of such processes.

Engineering economic analyses were performed for digestion of wheat straw, corn stover, and rice straw for various scales of operation. The results of the analyses indicate that the production of fuel gas from these residues is at best marginally economical. The use of pre treatment can double the gas output, but will not be justified economically unless low chemical requirements or low-cost chemicals can be used. It is interesting to note that the unit costs derived in the study were lowest for rice straw and highest for corn stover. This result was explained by the observation that gas produced from rice straw is about 50% greater than it is for corn stover or wheat straw. This higher output is due to higher residue content per hectare and higher biodegradable solids content in the residue.

The expanded use of anaerobic-digestion of rice straw is highly dependent on both the demand for methane gas and the price of competing energy sources such as natural gas. Due to the high transportation costs of manure and straw, agriculturally-produced methane is primarily used for on farm energy generation. In this situation, anaerobic digestion can potentially economically compete with natural gas in remote and isolated areas.

Commercial Development

The anaerobic-digestion process for production of methane gas is a proven technology using animal waste and municipal sewage waste. This technology is currently being applied commercially in California using animal wastes. A successful pilot scale project to investigate the feasibility of the anaerobic digestion process (and variations of the process) for the recovery of energy from municipal solid was conducted from 1990-1991 by the Department of Civil and Environmental Engineering at UC Davis (with funding from the California Prison Industry Authority).

A March 1997 presentation on Anaerobic Digestion of Rice Straw for Energy Recovery was made to the subcommittee by Ruihong Zhang of the UC Davis Department of Biological and Agricultural Engineering. A one year laboratory study by Dr. Ruihong Zhang confirmed the appropriateness of anaerobic digestion of rice straw. They concluded that the next steps to commercializing anaerobic digestion of rice straw is to investigate alternative approaches for pilot project demonstrations.

The UC Davis Department of Biological and Agricultural Engineering is seeking approximately $95,000 to fund a pilot scale project that would utilize rice straw. This is the next needed research to eventually commercialize the process.

Potential for Rice straw Diversion to Anaerobic Digestion

The opportunities for expanded use of anaerobic digestion of rice straw are limited by technological and economic constraints. This technology has not been applied to rice straw in a commercial endeavor, and needs further research before becoming an economic alternative that can effectively compete with existing energy sources. The Energy subcommittee concludes that further research is needed before anaerobic digestion of rice straw presents a significant opportunity for rice straw diversion.

Recommendations Concerning Energy Conversion of Rice Straw

The most promising use of rice straw for energy production is in the production of ethanol. Nationwide, there are a number of private companies as well as NREL that are actively pursuing the commercialization of biomass to ethanol technologies. A number of commercial plants are being proposed nationwide, including at least three in California. Two of the proposed California plants are to be located in the Sacramento Valley and would use rice straw as the primary feedstock. It is likely that at least one of the plants will be sited and in operation by the year 2000.

The advantages to California of encouraging increased use of rice straw-to-ethanol are significant. The advantages include reduced open-field burning, cleaner burning vehicles, increased employment in rural areas, decreased ethanol imports from the 20 ethanol-to-corn producing states, and decreased dependence on imports oil into California and the US. In addition the ethanol conversion process appears to have some intrinsic benefits. First ethanol conversion avoids potential air pollution problems associated with direct-combustion energy alternatives because no combustion is involved in the conversion process. However, although less significant there is oxidation with the digestion process that will create some impacts on “green house” gas effects. Ethanol production also requires energy uses that have to be analyzed on a case by case basis. Second, because the chemical conversion and distillation process results in the breakdown of rice straw into its constituent elements, ethanol conversion offers the potential for production and marketing of secondary products, principally silica and lignin. Though there are no proven markets for silica or lignin, there are some potential uses that must be assessed by rice straw users to determine economic viability (for example, lignin as a soil amendment and silica in the tire manufacturing industry).

Review of the market place shows that rice straw is not used in any of the potential energy markets. However, with rice-industry and government subsidies to address the financial barriers reference above, it is possible that future significant energy production uses could be made during the next ten years.

From an investor perspective, there is a high risk for the first commercial facilities of any new technology. The risks can be categorized into economic, environmental/permitting, technology and management/technical team credentials.

Investors assemble a “due diligence” or risk assessment review team to identify and analyze the risk of investing in a proposed project. If the identified risks are economically mitigatable, then the investors determine how to mitigate and spread the investment risks.

In addition, the investors then compare the levels of risk of investing in the new project, with the potential range of returns. In effect, does the risks correspond with the returns on investments. And most importantly, what are the fall back positions if the project doesn’t perform technically and economically as reflected in the business plan? Who stands behind the project; what are their assets? Does the project developer have access to additional capital, should the project fail to perform and run into cash flow problems? These and similar questions are of concern to potential investors or lenders in the market place; and they are often viewed as barriers by entrepreneurs and proposers of new technologies.

It is important that government agencies not replace the markets judgements as to who gets funded. Primarily because government is not driven to survive by making profits, and thus will never be good at assessing new technologies. Where the private capital markets are willing to invest in new technologies, a potential role for government is to share some of the risks with the private capital markets. This risk sharing can only be justified where the result will be significant public benefits. Government risk sharing on capital investments can reduce the time for getting a new technology in the market place. That is, in spreading the risks to the public sector based upon public benefits, the government sector can attract capital sooner in the market place.

It is important that the majority of funding for commercial facilities always come from the private sector. If the private sector is risking most of the money, they will make the final decision as to invest in a new technology, without allowing the government to change the criteria or the private sector judgement concerning the viability of a project in the market place. This approach can be accomplished by providing significant but minor loan guarantees or grants, to help the private sector spread the risks on new technologies.

To encourage energy production from of rice straw and to encourage the consumption of ethanol, the following actions should be considered by the State government and the rice-growing industry.

1. Private financial institutions are usually willing to finance between 50 to 60 percent of promising commercial projects for new technology applications if sound projects are developed. Developer-owners typically provide another 10 to 20 percent of the equity capital. To spread the new technology investment risk

among the beneficiaries of the new rice straw technologies (i.e., the developers, the investment banks and the public), legislation should be pursued to provide up to 30 percent loan guarantees for the first two commercial facilities (i.e., energy, manufacturing, etc.) of each new technology in the Sacramento Valley. Some potential state agency funding sources for the loan guarantees are the (a) California Pollution Finance Control Authority, (b) the Alternative Energy Financing Authority, and (c) the proposed funding in the CARB and CDFA draft report for growers to purchase burning rights.

2. It is recommended that state, federal and local governments encourage the use of rice straw ethanol for energy uses by: devoting research funds to improving the new technologies market efficiencies, conducting demonstrations projects to educate the potential consumers and end-user businesses of the uses of rice straw as an energy source, and providing regulatory support for environmental analyses that support the development of these technologies in the market place and give credit for their environmental benefits to California.

3. During the 1996 legislative session, legislation passed authorizing state tax credits for commercial users of rice straw: allowing $15/ton tax credits on a first come first served basis to be administered by the CDFA. The tax credit is limited to $400,000 each year. This would only address taking of straw from 8,888 of the 515,000 acres planted. In terms of having a significant impact by the year 2000, it would only address 1.8% of the problem. It is recommended that the dollar caps be removed to address the problem.

B. SUBCOMMITTEE REPORT - MANUFACTURING AND CONSTRUCTION

Rice straw is a non-wood cellulosic material that has potential for uses similar to other wood and fibrous non-wood materials. There are a growing number of technically feasible uses for rice straw in manufacturing and construction. These uses range from the direct use of straw bales for construction to very sophisticated molded composites for specialty automotive parts.

The Manufacturing and Construction Subcommittee examined a number of different options for diversion of rice straw into manufacturing and construction. These are grouped into two general categories describing two very different technological processes. In the first category are those options that require pulping. These options include the production of paper and cardboard, and most types of fiberboard, corrugated board, hardboard, and biomass molded products. The second category includes options that do not involve pulping, such as straw bale construction, certain types of board and composites, and straw-containing bricks, cement boards, or panels. The technological process and constraints, economic feasibility, extent of commercial development, and potential capacity of each type of manufacturing and construction alternative is examined below.

Pulp and Pulp Products - Paper, Cardboard, Boards, and Composites

Technological Process and Constraints

Pulping is a basic process used in the production of paper, cardboard, corrugated board, and most fiberboard, hardboard, and biomass molded products. Though each individual product involves different configurations after pulping, the overriding technological constraint in producing these products from rice straw appears to be the pulping process.

Pulping changes raw materials to a fibrous form capable of being shaped and bonded into desired products. (For a more comprehensive review of the pulping process, see Haygreen and Bowyer [1989].) Pulp production typically takes place in three steps: 1) sorting and cleaning of raw materials; 2) material sizing; and 3) fiber alteration or fragmentation, including lignin removal. These processes may occur separately or in some combination during product manufacture.

The desired physical and chemical properties of pulp vary with the intended end-product. Pulp products may range from soft and pliable to hard and rigid. Materials which affect color, strength, rigidity, water resistance, etc., of the product may be added in the manufacturing process. There are numerous processes for production of pulp and pulp products.

In commonly used chemical pulping processes, plant biomass is subjected to alkaline chemical "cooking" where an alkaline chemical such as aqueous sodium hydroxide, at pH 11 or above, is applied to remove lignin and facilitate fiber separation. The alkaline treatment also dissolves silica. The amount of silica dissolved depends on the amount of alkali used in the cooking process. Under high alkali conditions, about half of rice straw silica can be removed (Kopfmann and Hudeczek [1988]).

The liquefied alkaline material, or "black liquor", containing silica and lignins, is separated from the fibrous pulp and subjected to chemical recovery of alkali content in order to produce pulp economically and to meet environmental restrictions. For plant materials like sugarcane bagasse, the alkali recovery can approach 90%. However, due to the large amount of silica in rice straw, silica sludge (or mud) in the black liquor creates difficulties with virtually all stages of the chemical recovery process -- even preventing the installation of a chemical recovery system in some cases (Kopfmann and Hudeczek [1988]).

Extensive study of the digestion process for rice straw and bagasse has resulted in improved ability to recover process chemicals. Lowering the black liquor pH (9.7 to 10 range) promotes precipitation of silica and lignins. Precipitation results in a gelatinous material removable by centrifugal separation. Although this process results in substantial improvement of silica removal over other methods, residual silica cannot be reduced entirely. High silica black liquor handling has improved to the point of allowing large scale processing plant operation (Indonesia). Disposal of the silica sludge remains an issue (Atchison [1988] and Kopfmann and Hudeczek [1988]).

The silica sludge produced by rice straw during the pulping process imposes added processing and disposal costs. To date there are no technologies for completely eliminating silica sludge nor are there environmentally neutral alternatives for the disposal of the sludge. In areas of the world where wood and other more suitable agricultural residues are readily available, the technological constraints posed in pulping rice straw have proved economically restrictive.

Product formation after pulping for cardboard, fiberboard and composites may involve: 1) binder incorporation; 2) forming -- e.g., sheet formation; 3) pressing -- to achieve density and express excess liquid; 4) pressure and thermal treatment -- to promote chemical bonding; and 5) cooling and finishing -- e.g., surface sanding. Any fibrous plant product, including composites and some fiberboard, requires chemical binding of materials to attain a finished product. The binding of molecules reduces component movement within the material, resulting in increased rigidity and strength. The binding results in stability and retention of shape. Lignin-cellulose components of biomass can inhibit polymer formation in composites. Pretreatment of non-wood fibers may be needed to enhance binding in composite formation. For example, wheat straw subjected to a steam explosive process demonstrated changes in the lignocellulosic components that enhanced the interaction with a binding material, poly-3-hydroxy-butyrate (PHB). The product, containing 10 to 20% straw had distinctly better mechanical characteristics than with wood and PHB alone (Avella et al. [1993]).

Like other straws, rice straw will probably require pretreatment to enhance binding. In addition to the lignin-cellulose content of rice straw, the abrasive nature of the high silica content in rice straw will impose added equipment and treatment costs for the processing of rice straw over other materials. Again, in areas of the world where wood and other more suitable agricultural residues are readily available, these added costs could severely restrict the use of rice straw in manufacturing processes that require binding.

Economic Feasibility

The economic feasibility of any product that requires the pulping of the rice straw is severely constrained. Among non-wood fibrous plant materials available for pulping and pulp products, rice straw contains the highest level of silica. High silica content contributes to difficulty in handling rice straw; it is abrasive and rigid. Silica residues in pulping residuals make process chemical recovery more difficult. High silica black liquor sludge increases waste disposal costs. These factors have historically resulted in increased manufacturing costs and created economic disincentives for the use of rice straw when other less demanding materials are available. In processes that require binding, these difficulties are compounded; the lignin-cellulose content of rice straw in addition to the abrasive nature of the high silica content in rice straw will impose added equipment and treatment costs for the binding of rice straw products. There are currently many superior, less expensive inputs competing with rice straw in any technological process that requires pulping.

However, Arbokem, Inc., a Canadian company, has developed a pulping process to produce Agri-pulp™. The straw is digested with a mixture of potassium sulphite and potassium hydroxide. This resulting material is then bleached with hydrogen peroxide. The byproducts of potassium sulphate and organic materials are then used in the preparation of fertilizers. Arbokem, Inc. indicates that enough silica is removed by this process that the technological and economic constraints described above can be overcome.

Commercial Development - Rice straw Pulp Mills

Though non-wood pulping is expanding in other areas of the world, the use of non-wood pulping materials has decreased in the United States over the past several decades. The decline of non-wood pulping in the United States is primarily due to the extra costs associated with straw (or other input) processing and the abundance of inexpensive wood inputs.

The subcommittee was unable to document any commercial rice straw pulp mills in the United States. Agri-pulp™ was prepared in Canada, however, to date, there is no known commercial use of the pulp other than the test newsprint run described below.

Development of rice straw pulping in the United States entails further research into alternative methods of rice straw pulping and assessment of any unique products that could be developed due to the unique fiber characteristics and silica content of rice straw. If rice straw pulp and pulp products could be manufactured without removing silica, rice straw would be a more attractive raw material.

Commercial Development - Paper and Cardboard Production

Economic rather than technological factors appear to have constrained the commercial development of paper and cardboard construction in the United States. Commercially, straw preceded the use of wood as a raw material for paper making. Wood was first pulped in China for paper in 105 AD, though straw, linen and cotton rags were primarily used for paper-making until 1844 when wood became the more important fiber source (Haygreen and Bowyer [1989]). Pulp of various sources can be used for paper and a host of fiberboard products. Nearly every pulpable material will provide a product with some desirable properties. However, of non-wood biomass materials, only straw, bagasse, and bamboo are likely to provide sufficient quantities of material to be economically viable. As pulp wood costs escalate, alternative fibers may become economically feasible for pulping. The most promising non-wood plants include: sugarcane bagasse, cereal straws (including rice), seed-grass straw, grain sorghum stalks, kenaf (sunn hemp) and crotalaria (Atchison [1988 and 1992]). In the United States, the abundance of superior inputs (i.e. wood) has all but eliminated the commercial production of paper and paper products from rice straw.

Increased environmental awareness and increased demand for paper have heralded an increase in paper-recycling and may also improve the marketability of non-wood fibrous materials for paper. In Egypt, waste paper has been homogenized with digested straw (type of straw not specified) prior to paper making (Hamza [1989]).

Further concern for environmental sustainability or further increases in demand for paper could eventually provide the catalyst for the commercial development of rice straw paper in the US. From a technical point of view, any grade of paper can be produced using various combinations of non-wood plants[1]. Their greater use awaits only the economic necessity (Atchison [1988]).

For many years, the commercial development of rice straw paper production on the West Coast was restricted to a study on the feasibility of corrugated paper production, and an ill-fated corrugated paper plant. In the early 1980's, the Rice Research Board and Louisiana Pacific joined in a study on the technological and economic feasibility of corrugated paper production. The study indicated that the market was inadequate to support a production facility on the West Coast. A plant producing corrugated paper from rice straw was established in California but closed in 1989 (Moss et al. [1993]).

In 1996, Arbokem, Inc. and Smurfit Newsprint, of Oregon, developed and tested standard newsprint using Agri-pulp™. In this case, the pulp was a blend of rice straw, rye straw, and fescue straw residuals. The Agri-pulp™ was blended with other pulps at 10% and 20%. The resulting newsprint was tested at six newspaper facilities and one commercial printer. Both blends ran on the presses and printed in a satisfactory way. Smurfit Newsprint concludes that Agri-pulp™ may be a good pulp for newsprint, but that further research is needed in terms of optimal blends of straws and effects on equipment.

Commercial Development - Fiberboard Production

The primary difference in the process for making fiberboard from straw instead of wood is the difference in resins (chemical binders) used. Working with lignin-cellulosic materials requires pretreatment and special binding agents. These binding agents represent a fairly new technology. For example, a light-colored phenol-formaldehyde resin has been developed which, when cured, has a light color and gives an attractive light buff-color board from materials such as rice husks, rye grass and wheat straw. Polyisocyanate resins have also been used to make particle board from straw (BPNL [1982]).

Rice straw has been used in experiments for production of medium-density fiberboard. This experiment involved a mixture of 50/50 of rice straw and California hardwood chips. Rice straw was deemed “a difficult material to work with” (California

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[1] An added constraint in the marketability of rice straw paper is that the bleaching methods suitable for paper production from wood pulps or other agricultural residues may not be suitable for rice straw pulp. However, satisfactory bleaching processes appear feasible though further study is warranted (Zeronian et al. [1981]).

Rice Growers Association [1984]).

Despite the difficulties in processing rice straw, NMC Corporation of Texas (who developed the FiberTech Colusa 1, LLC project) has constructed a facility to build a medium-density fiberboard that is made using rice straw. The facility is located in Colusa County, and will process 7,000 acres of baled rice straw annually (21,000 tons of straw). Fibertech Colusa 1, LLC is storing rice straw at the Colusa County Airport. The facility will produce medium density fiber products that are primarily used to build furniture. CRIA reports that worldwide demand for medium density fiber products has risen 230 percent in the last decade.

Commercial Development - Composites

“Composite”, as generally used in describing forest products, refers to combinations of veneers and particle boards in panels and lumber (Haygreen and Bowyer [1984]). With the introduction of new methods and materials, the term “composite” has come to include materials manufactured from plant biomass but containing substantial amounts of non-fibrous components, such as plastics. Future composites could be a variety of wood/non-wood mixtures. Possible non-wood materials include paper, plastics, and plant fibers (cotton, straw, almond, walnut, flax, bamboo, bagasse, etc.). Through composites, improved adhesives and pressing techniques will allow for the more efficient use of wood (Blackman [1993]). In addition, composites can result in better structures than standard timbers, e.g., in the production of veneer-based laminated composition materials such as I-beams.

Despite the difficulties inherent in pulping and binding rice straw, at least one commercial project utilizing rice straw in composites has been proposed. PACO, registered trademark of Particle Compacting Development, Limited, is a commercially available composite fabricating system. PACO can utilize plant biomass waste of a wide variety. This proprietary process utilizes the natural "plastics" found within the sized biomass raw material thereby using the biomass itself as part of the bonding or adhesion process. The way in which PACO accomplishes this is proprietary, and is not specified in literature from the company. Potential products include pallets, sheeting, boards, tiles, furniture, blocks, irrigation piping, etc. A company representative contends that PACO could commercially process any and all available rice straw, husks or other waste material on an annual basis, the only constraint being the number of plants and the amount of capital available for construction purposes. PACO representatives indicated that plant would cost $1,500,000 or more depending on the quantity of feedstock available, but provided no other cost information. PACO has processed substantial amounts of wheat straw in both the United Kingdom and South Africa. It has also conducted extensive tests, with excellent results, using California rice straw.

Potential for Rice straw Diversion to Pulp-Based Manufacturing

The potential for significant diversion of rice straw to pulp-based manufacturing is comparatively low. FiberTech Colusa 1, LLC estimates that it could process 7,000 acres of baled rice straw annually in fiberboard production and PACO estimates that 30 to 100 thousand tons of rice straw could be processed annually, but neither company has yet to actually process straw. Recent attempts to contact PACO were not successful.

Due to the difficulties in pulping rice straw and in binding rice straw, other wood and non-wood residues seem more suitable for manufactured products.

Non-Pulping Alternatives - Composite Manufacturing from Rice Straw

A number of possible technologies that do not include pulping exist for the production of composites or fiberboard. The technological process and constraints, economic feasibility, commercial development and potential of this alternative are examined below.

Technological Process and Constraints

This product area has seen the most new companies appear with potential applications using rice straw. Following are descriptions of companies with proprietary technology that are looking for opportunities to site commercial facilities in the Sacramento Valley using rice straw as a feedstock.

The patented Agronomic Systems process utilizes 70% biomass and 30% recycled plastic to produce a wood replacement material marketed as BioComp. The manufacturer indicates that this material is stronger than most species of wood. The material is also stated to be waterproof, resistant to rot and insects, withstand sun, and retain color. In addition, like wood, this material can be shaped and nailed.

Agronomic Systems' literature states that BioComp, which stands for "biological composite," is created by mixing "exploded" biomass with recycled plastic such as plastic milk and coke bottles. The patented "steam explosion" process breaks apart the biomass, much like a kernel of popcorn, in order to efficiently release the starch, sugars, resin, and other raw materials of the fiber. Agronomic Systems states that this process works on nearly any long cell biomass, including wheat, rye, corn, rice, and barley straws, and sugar cane, sorghum, wild indigenous grasses and even young spruce and poplar trees.

U.S. Biomass Technologies also possesses a technology which uses straw and recycled plastic to produce pallets and similar products of composite structural lumber. The company claims that the product is water, weather, UV, and insect resistant. In addition, U.S. Biomass Technologies plans to produce a fiber for use in injection molding manufacturing. It was not indicated whether or not that technology involved a pulping or composite process.

Pinnacle Technology offers a plastic/fiber technology (agro-plastics) that has completed two years of R&D on the technology using wheat straw as the primary fiber. The work was performed with USDA's Forest Products Laboratory under an ongoing Cooperative Research and Development Agreement. The company has developed engineering designs for a pilot facility, conducted initial test manufacturing trials, developed a business plan and conducted market surveys for the resulting product. They are testing four grades of product; two using a polypropylene/straw feedstock and two using a polyethelene/straw feedstock. The manufacturing test should be complete by Fall 1997.

The agro-plastics pellets produced by Pinnacle are suitable for direct injection molding or extrusion. They have developed the products for the low end, high volume plastics market to manufacture items such as garbage pails, handles, in/out trays molding, picture frames ,etc. In Kansas, Pinnacle is working with the wheat straw farmers to identify either items that are plastic or local plastic companies that could use the agro-plastic pellets.

Sigma Tek and its West Coast Relocatables of Sacramento, have specific markets with committed interest in the use of products made from Unwood technology, a composite product for construction and transportation markets. According to Sigma Tek, they have designed a prototype plant using Natural Engineering's proprietary processes. The proposed prototype facility would use rice straw as its primary feedstock.

Economic Feasibility

The Agronomic Systems stated that the cost of manufacturing BioComp composite is $230 to $260 per ton or 12 to 13 cents per pound. The selling price would be a minimum of double the production cost or up to $0.52 per board foot (a ton of BioComp is about 1000 board feet). However, selling price will be affected by competing products costs. The proponent estimates each $2,000,000 plant would be paid for in 4 to 5 years.

U.S. Biomass Technologies states that $250,000 is needed for final product tests. Additional investment will be required to bring the company to full production.

Additional information on the other companies was not available at the time of printing this report.

Commercial Development

BioComp estimated that each plant would use up to 14,000 tons per year and service 3 to 5 thousand acres of straw-producing land. The pilot plant for BioComp is located in Montrose, Kansas doesn't appear to be in operation Future development is yet unannounced and the subcommittee was unable to contact a representative.

U.S. Biomass Technologies, Inc. plans to build a 50,000 square foot manufacturing building in Sutter County. U.S. Biomass stated that if the needed funding is obtained, the plant site could be ready by November 1997 and production will begin in the first quarter of 1998. They estimate that this first plant will convert 50,000 tons of rice straw annually into fiber for manufacturing.

Pinnacle Technology is raising funds for a pilot facility (3 tons/day) to be built in Kansas. They have also completed the design and economic analysis for a commercial facility that would use 15 tons/day or 2400 tons of straw per year.

Non-Pulping Alternatives - Straw in Construction

Potential uses of straw in California construction include: 1) straw-containing bricks; 2) straw-containing cement boards; 3) panels made of straw, 4) straw-containing tile, and 5) bale straw construction.

Technological Process and Constraints

The technological processes involved in transforming rice straw into construction materials include baling, rolling, incorporation of the straw into cement, and extrusion (a process involving pressing, heating, wrapping, cooling and cutting). These alternatives represent low technology approaches to alternative uses of rice straw, with straw bales the lowest. Nevertheless, even where minimal processing is required, the physical and chemical characteristics of rice straw make it a relatively high-cost input. The high silica content of rice straw makes it tough and abrasive and difficult to process. But, the natural toughness of the straw adds durability, a positive quality in building and manufacturing.

Economic Feasibility

In the US, economics has not typically been the primary concern motivating the development of straw construction. The abundance and practicality of alternative building materials have relegated straw construction to a small fringe market. With an increase in concern for environmental sustainability or an increase in the cost of wood, straw construction could gain in popularity.

Commercial Development - Bricks and Cement Boards

Fiber reinforced building materials have been used for centuries in the form of bricks and other products, however, when combined with cement, the alkalinity of cement can have adverse effects on the long-term durability of natural fibers. However, a study has indicated that alkalinity can be controlled by various additives (Sera [1990]). In Europe, cement-bonded wood-containing boards with up to 75% cement have been produced for interior and exterior walls and decking. However, the material is heavy and difficult to handle, cut and fasten (Haygreen and Bowyer [1989]).

Rice straw has been evaluated for its mechanical properties in straw-clay composites. While the produced material was a good insulator, it was not waterproof. Rice straw has also been used to bind clay in built-up walls as well as manufacture of brick for firing. Firing of straw-clay composites results in biomass loss which can result in a lighter weight product and improved insulation properties (Beagle [1981] and Sera [1990]).

The subcommittee was unable to document any commercial production of rice straw brick in California. However, a California company, FiberCrete, has plans to produce either tiles or bricks using rices straw. This plant will be located in the northern California rice producing area. See further discussion of FiberCrete below under tiles.

Commercial Development - Panel Construction

Manufacture of straw panels or boards was pioneered in Sweden in the 1930s and patents were issued in the 1905 to 1937 era. However, commercial production did not occur until 1941 in Germany (Haygreen and Bowyer [1989]). Straw panels are being produced in a number of areas of the world including Belgium, Australia, China and the Philippines (Bryce [1994]).

The "thick" panel production machines were developed by the Stramit company in England about fifty years ago and sold worldwide. "Thick" panel production is a continuous extrusion process that involves compression, heating, wrapping, cooling and cutting. No pre-treatment of the material other than cleaning, loosening and spreading prior to compressing is required. Stramit USA out of Perryton, Texas, offers EnviroPanels at $18.99 per panel measuring 4 feet by 8 feet, to 26.99 per panel measuring 4 feet by 12 feet. A 4 foot by 8 foot EnviroPanel weighs 140 pounds.

Stramit USA currently uses wheat straw though the process has been adapted to rice straw for production in other areas of the world (Information based on a letter from Strammit USA).

A thicker straw paneling produced by PYRAMOD International, City of Industry, California, is used in a unique monocoque structural system for single story buildings. The PYRAMOD system makes mass production of housing structures feasible using straw as the basic raw material. The PYRAMOD panels are 4 to 5 inches thick, compared to the 2 inch panels previously used solely for insulation. The pre-cut shapes are joined by adhesive and fiberglass tape to form frameless monocoque structures. Seismic stability is outstanding as demonstrated by testing done at California Institute of Technology. Thermal and sound insulation is also stated to be excellent. The structures were designed to meet 1988 Uniform Building Code requirements for load conditions. The pre-cut panel shapes are sold as a part of a kit that includes a weatherproof coating for the exterior walls. PYRAMOD structural kits sell for about $10 per square foot and completed PYRAMOD homes have been built in the $30 to $40 per square foot cost range, which is very competitive in cost to conventional construction. Annually, one extrusion machine produces paneling sufficient to build housing structures of 1,000,000 square feet of floor area using 10,000 tons of straw. While rice straw may be amenable to PYRAMOD panel production, this has yet to be tested. Recent attempts to contact PYRAMOD were unsuccessful.

BioFab, LLC, located in Redding, California is promoting a straw panel, Pacific Gold Board. This straw panel can use rice or other straws for raw material. The panel is an alternative to sheetrock. It is also used in doors, pallets, archery targets, office screens, furniture, and packaging. The technology came from Europe and is in use at a few commercial manufacturing locations in Europe, Canada, the U.S., and South America. This particular technology is developed for using straw, instead of general biomass or wood waste materials. The uniqueness of the board is that it is portable and can be moved from area to area on two semi-trucks.

BioFab, LLC has a similar product, Pacific Gold Board 3, that is used as an acoustic aesthetic material for walls and ceilings. It can also be used as a water plant filter or for fences.

Tests have been conducted using rice straw as the feedstock, with successful results according to William Martens, Projects Manager. However, BioFab, LLC currently makes no commercial use of rice straw. Estimated investment costs to produce Pacific Gold Board using rice straw are $1 to 4 million. This size facility is estimated to process 20,000 tons or approximately 7,000 acres of rice straw annually.

Commercial Development - Tile

FiberCrete has developed a tile made of 30 to 40 percent rice straw. The tile looks similar to cedar shake. It is currently being tested. FiberCrete plans to produce the tile in Encinada, using northern California rice straw. Production may begin by late summer of this year. Estimated usage is between 60,000 and 100,000 tons per year of rice straw.

Commercial Development - Bale Construction of Homes and Small Buildings

Straw-bale construction was used in the Midwestern United States in the late 1800s and early 1900s and the technology is currently enjoying a renaissance driven by housing costs and ecological issues. Straw bales are dimensionally in the range of 16 x 18 x 36 to 16 x 23 x 42 inches and weigh 50 to 80 pounds or more. A house 32 x 32 x 8 feet (1024 square feet interior) requires 226 bales of 42 inch length for exterior walls. At 80 pounds per bale, this corresponds to about 9 tons, or the straw from 3 acres. Straw bales can also be used for a variety of non-dwelling structures such as sheds, lambing or animal shelters, utility buildings or garages (Bainbridge [1993]).

The cost of a straw-bale home depends on many variables. Wall costs account for about 20% of standard construction costs. Bainbridge (1993), estimates that a bale wall will be one third to one half of the cost of a super-insulated wall of conventional materials and slightly less than a standard, poorly insulated wall. Owner-builders should be able to realize substantial saving from less labor costs. Walls for an entire house have been erected in a single day. Bale-wall homes have been built for $10 to $100 per square foot (Everett [1993] and Haederle [1993]). The lower cost range appears related to “owner-built” structures that do not reflect labor costs; owner-built homes costing as little as $4,000 have been cited in the popular press (Everett [1993]). In addition, costs of straw bale homes may be partially offset by expected energy savings due to the insulating effects of bale walls.

There is presently little information on building code conformance for straw-bale structures. Although straw bales appear to have potential as a building material, it is essential that bales be produced to meet or exceed minimal standards for density, binding and other parameters. Other wood products must meet standards such as the International Organization for Standardization (ISO) Standards Handbook 23, 1984: “Paper, Board, and Pulps” (Bainbridge et al. [1993]). Straw-bale structures have been evaluated in Canada and Pima County, Arizona. Pima County has draft standards for straw bale dwellings (Pima County Building Codes [1993]).

During 1995, the State of California adopted safety guidelines for the construction of straw bale structures. The purpose of the guidelines is to provide flexibility to existing building standards.   However, the new law still requires that plans and specifications for such structures be prepared under the direct supervision of a licensed architect or civil engineer. the law also requires the California Building Standards Commission to report to the Legislature on the implementation of the bill by the year 2002. Interest groups have proposed testing parameters for straw-bale construction (Bainbridge et al. [1993]).

Two counties, Yolo and Colusa, have submitted ordinances to the Department of Housing that adopt the guidelines in last year's legislation concerning rice straw bale construction.

However, straw bale construction has yet to be thoroughly evaluated from an engineering standpoint in terms of moisture, seismic safety, bearing ability, durability, and insulation. It is not included in the building inspectors' "bible" known as the International Conference of Building Officials Field Index of Evaluation Reports. This is what a building inspector may cite when giving approval for construction. Absent this citation, the official has little to stand on in terms of ensuring seismic safety and performance of the materials.

Limited testing of wheat straw bale wall structures has been carried out at the University of Arizona in the Department of Civil Engineering and Engineering Mechanics. A Master of Science thesis by Ghailene Bou-Ali indicated that wheat straw bales had sufficient strength and load-bearing capabilities to serve as load-bearing walls (Bou-Ali [1993]). Bales were found to have other potential beneficial properties such as increasing strength with compression and ductile failure properties (as contrasted to abrupt or brittle failure) (Bou-Ali [1993]).

The R value of straw bales has recently come into question. The California Energy Commission has found fault with the data supporting the long-believed high R value.

Despite these problems, some construction has proceeded. Several homes have been built with straw, including a farm worker housing project in Contra Costa County. A commercial facility was constructed of rice straw in Colusa County. A home in Calaveras County and a visitor center in Angels' Camp have been built using rice straw.

In its previous report, this subcommittee recommended that the State Department of Transportation and the City and County Highway Departments in the Sacramento Valley investigate the possibility of constructing highway sound walls using rice straw as a building material.

Last year a contract was executed between CalTrans and the Integrated Waste

Management Board (IWMB) for the IWMB to conduct a rice straw sound wall evaluation project. The IWMB anticipates that the wall will be constructed by fall of 1997. The wall will be 150 feet by 12 feet (one bale thick). It will be constructed with chicken wire, external steel cladding and gunnite. The evaluation period will last for three years, during which time the wall will be monitored for leaks and structural problems.

Potential for Rice straw Diversion to Building

The efforts described above are commendable and promising. Use of rice straw for these purposes does, however, appear to be limited to these types of special projects at this point.

Construction of straw bale houses utilizes modest amounts of straw; a house of 1000 square feet interior floor space utilizes the straw from 3 acres of rice at 3 tons per acre. In order to divert ten percent of the yearly rice straw production, approximately 15,400 rice straw houses would need to be built each year (about 5% of California housing starts for 1986). It seems unlikely that straw-bale construction would make substantial inroads on the need for straw disposal in the foreseeable future. In addition, there is very limited information on rice straw in these uses.

Mass production of rice straw panels for modular home construction appears to be a viable technology with a potential market. Both Pyramod and BioFab, LLC have demonstrated some degree of commercial feasibility with straw.

Conclusions and Recommendations Concerning Manufacturing and Construction using Rice Straw

The technologies for using rice straw in the manufacture of buildings and structures, pressed boards for structural uses, pulp and composite materials have been proved feasible. However, for those technologies that require pulping or binding, rice straw is a difficult feedstock to work with. The unique properties of rice straw, particularly its silica content, pose unusual challenges for manufacturing uses. However, economic and regulatory factors rather than technological factors may be the major obstacles for increased manufacturing uses of rice straw. Cereal straws, including rice straw, are increasingly used in manufacturing worldwide where wood is either not available or prohibitively expensive. Unless there is some unique development pertaining to rice straw, economic constraints make significant increases in manufacturing use of rice straw in California, or elsewhere in the United States, unlikely at this time. Economic change could result from increasing costs of other materials or subsidy for rice straw utilization or some combination of both.

Rice straw has potential as an input into the construction market, but until such time as straw bale structures are adequately evaluated and widely accorded legitimacy under the Uniform Building Code and other applicable regulations, it is unlikely they will achieve significant inroads into the housing market. Development of standards is being pursued in California and other States.

Straw bale wall structure may have significant promise where bales are available at reasonable costs. Agricultural areas generating large amounts of cereal straw would seem to be a natural market for this type of structure. Low cost housing needs can be addressed, in part, by lower cost locally produced building materials.

Review of the market place shows that minimal uses are currently being made of rice straw in the potential manufacturing and construction markets. With or without direct government subsidies, it is unlikely that significant volumes of rice straw will be used by the year 2000. The primary barriers are the inability to compete economically with other substitute materials, the typical inertia of the market place that resists change because of the uncertainties and related risks of switching to new raw materials, and the lack of public citizen, elected officials, and public agency knowledge of the technologically feasible potential applications. With government intervention to address these three barriers, it is possible that future significant manufacturing and construction uses could be made during the next ten years.

The subcommittee recommends state and local government agencies in the Sacramento Valley do the following to encourage the future manufacturing uses of rice straw:

1. *The State Air Resources Board and the Department of Food and Agriculture should consider partial subsidies for using rice straw in manufacturing.*

2. *The Air Resources Board, Department of Food and Agriculture, the California Energy Commission, the rice industry, and the Sacramento Valley cities and counties should jointly support continued efforts to establish appropriate construction standards for rice straw building construction, particularly for barns, equipment sheds and other agriculture related facilities. Jointly funded demonstration projects would help educate the public, regulatory agencies and potential commercial market users on the use of rice straw in building construction.*

3. *Private financial institutions are usually willing to finance between 50 to 60 percent of promising commercial projects for new technology applications if*

sound projects are developed. Developer owners typically provide another 10 to 20 percent of the equity capital. To spread the new technology investment risk among the beneficiaries of the new rice straw technologies (i.e., the developers, lending institutions and the public), legislation should be pursued to provide up to 30 percent loan guarantees for the first two commercial facilities (i.e., energy, manufacturing, etc.) of each new technology in the Sacramento Valley. Some potential state agency funding sources for the loan guarantees are the (a) California Pollution Finance Control Authority, (b) the Alternative Energy Financing Authority, and (c) the proposed funding in the CARB and CDFA draft report for growers to purchase burning rights. This recommendation should apply to all new technologies, including the manufacturing as well as the energy.

D. REPORT OF THE SUBCOMMITTEE ON ENVIRONMENTAL MITIGATION

Environmental mitigation in this context means the use of materials, such as rice straw, for erosion control and fire rehabilitation. Uses include erosion control at construction sites and road projects and erosion control and/or rehabilitation at wildfire sites.

The Subcommittee on Environmental Mitigation considered the potential of erosion control and fire rehabilitation programs to divert rice straw. This report examines the technological constraints, economic feasibility and commercial development of using rice straw in environmental mitigation projects. This report also examines the potential capacity of environmental mitigation for diverting rice straw and presents recommendations to support the growth of this use.

Technological Constraints

The California Department of Transportation, California Department of Parks and Recreation, California Department of Forestry and Fire Protection, U. S. Forest Service, U. S. Park Service, local road departments, Resource Conservation Districts, private timber companies, mountain-area land owners, and development site contractors all use straw for erosion control on construction areas and for rehabilitation of burned areas. The straw can be spread unbaled (loose) over these areas to provide protection to fragile soils, or it can be bundled to provide heavier defense against run-off and erosion.

A number of field experts expressed their preference for rice straw for erosion control because rice straw is heavier and more durable than other straws. This durability is due to the comparatively high silica content of rice straw. For these types of uses the silica content of rice straw is an asset, whereas for other potential uses described in this report, the silica content of rice straw is a drawback. In addition, rice straw is less likely to harbor noxious weeds than other straws. This is because the weed seeds in rice straw are typically aquatic rather than terrestrial.

The primary disadvantage associated with rice straw is its seasonal availability. Erosion control and fire rehabilitation projects take place year round and are often scheduled with little advance warning. These projects must have access to relatively large quantities of straw throughout the year. Wheat straw is typically used when rice straw is unavailable.

Economic Feasibility

The market for rice straw in erosion control and fire rehabilitation has already been established and rice straw, as long as it is available, has little competition from other sources of straw in this market. In addition, the demand for rice straw in soil erosion and fire rehabilitation projects is steady over the long term and is not expected to decline.

The infrastructure has not been sufficiently established for supplying the market on an as needed, immediate turnaround basis. Currently, the marketing mechanism for rice straw, including straw collection, transportation and storage, appears to be the major constraint in establishing a more solid niche for rice straw in the erosion control or fire rehabilitation markets.

Depending upon the season and the onset of rain, there can be a rather short time period in the fall when rice straw can be cut and baled. However, there is some indication that straw left behind after stripper header harvesting may still be cut and baled in the spring.

Commercial Development

There are a number of established balers who provide rice straw for erosion control and fire rehabilitation. The subcommittee has talked to two vendors that bundle the straw in addition to selling it in bales.

In Placer County, the USDA Farm Services Agency (FSA) and the Natural Resources Conservation Service (NRCS) along with the FSA County Committee and Placer County Resource Conservation District (RCD) developed a cost share program to encourage Placer County rice growers to cut and bale their rice straw. The High Sierra Conservation and Development Council (RC&D) worked jointly with the above organizations and rice growers to promote the use of rice straw for erosion control on construction sites.

In 1996, the High Sierra RC &D and Placer County rice growers who participated in a special cost share program developed by USDA – FSA and NRCS, began a project to supply rice straw for erosion control at construction sites. Growers sold 1500 tons of straw for varying prices. Some made a profit. Demand exceeded availability. Growers and the agencies are working to facilitate the formation of a cooperative to stabilize prices and meet demand.

Potential for Rice straw Diversion to Environmental Mitigation

The potential capacity of erosion control and fire rehabilitation projects to use rice straw is relatively small compared to the amount of straw that is potentially available. However, the market is established. It is difficult to estimate current use-rates for straw in erosion control and fire rehabilitation projects, and therefore the subcommittee decided to refrain from estimating future use.

Recommendations Concerning Environmental Mitigation

1. *The subcommittee recommends that state, federal and local governments, and the rice industry itself, encourage the use of rice straw for environmental mitigation, educate the potential consumers and end-user businesses of the uses of rice straw as a raw material, and provide regulatory support for environmental analyses that support the development of this application in the market place and give credit for the resulting environmental benefits to California.*

   As stated above, the High Sierra RC&D, Placer County rice growers, and the FSA for Placer County worked jointly on a project to promote the use of rice straw for erosion control at construction sites. The subcommittee strongly recommends that these agencies and growers continue to work together towards the formation of a cooperative or similar effort to stabilize prices and meet demand.

2. *Much of the environmental mitigation work on roads and fire rehabilitation is under the direct control of state, local and federal agencies. Therefore CARB and the CDFA should assess the need and identify how to target the governmental agencies involved in planning and implementing environmental mitigation, to optimize rice straw use in their rehabilitation efforts.*

3. *The subcommittee recommends that funds be budgeted in one or more state agencies, for example CDF, to make straw available on an on-going basis. Such agency could contract for this service. If properly stored after cutting and baling, the straw could be transported on demand for erosion control or fire rehabilitation conducted by that agency.*

E. REPORT OF THE SUBCOMMITTEE ON LIVESTOCK FEED

The Subcommittee on Cattle Feed examined the potential of diverting rice straw for use as a component in livestock feed, particularly cattle feed. Though research has shown that rice straw can be suitable as a feedstock for ruminants on weight maintenance regimes, other sources of feed continue to be better suited to all of the nutritional needs of livestock. The Subcommittee on Livestock Feed examined the technological process and constraints inherent in adapting rice straw to feedstock; the economic feasibility of rice straw vis-à-vis other feedstock feed components, the commercial development of rice straw based feedstocks, and the potential of this alternative. The primary scientific findings of the subcommittee were based on a 1992 article by Garret and Dunbar entitled "Rice Straw as a Feedstuff for Ruminant Livestock." This article summarizes a number of studies on the suitability of rice straw as a component in livestock feed. Original sources are also cited below.

Technological Process and Constraints

Rice straw is by nature coarse and of limited nutritional value. The total fibrous material in rice straw is high, and the crude protein content is low, meaning that rice straw does not supply enough nitrogen for the efficient metabolism and growth of rumen microbes necessary to carry out the initial breakdown of the straw (Garret and Dunbar [1992]). In addition, the high silica content of rice has no nutritive value and may interfere with the digestive process. Rice straw is poorly digested in comparison with alfalfa hay, 42-48 percent of rice straw as compared to 65-70 percent of alfalfa hay is digested by cattle (Garret [1978]). In addition, the digestible energy content of rice straw is low in comparison with traditional cattle feed. The digestible or metabolizable energy content is only 60-65% that of alfalfa hay. When additional losses associated with animal metabolism are considered, the value of rice straw as compared to alfalfa hay drops to 45% when used for maintenance and less than 20% when used for ruminant growth. Very poor or damaged rice straw can be worthless, even for weight maintenance (Garret and Dunbar [1992]).

As reported by Garret and Dunbar (1992), rice straw has its greatest value as a major component of diets formulated to maintain the unpregnant and pregnant mature ruminant. For these ruminants, the requirements for energy and protein are small compared to their capacity to consume feed. Hull et al. (1978) found that diets composed of 75 and 85 percent rice straw (properly supplemented) were adequate to support pregnant cows and result in normal birth weight calves. The performance of the cows and calves in the Hull et al. experiment was comparable to those kept under conventional management practices on dry range or on irrigated pasture for an equivalent period of time.

A wide range of processing procedures have been used experimentally in an effort to improve the feeding value of rice straw. The treatments can be grouped into physical, chemical, or biological treatments. Each treatment type will be examined below.

Physical treatments include chopping, grinding, pelleting, steaming (with or without pressure), soaking or wetting and gamma irradiation. Of these methods, only chopping, grinding or pelleting are viable treatments for rice straw. However, these methods were designed to facilitate feeding and reduce wastage, and could result in decreased digestibility in cases where these techniques lead to an increased rate of passage of the food particles through the animals digestive tract. In addition, the elastic nature of rice straw makes it more resistant to grinding and pelleting than other cereal straws, and binders may be necessary to produce good quality pellets or cubes (Hull et al. [1972]).

Chemical treatments have been used to increase cell-wall degradation in rice straw and hence increase the digestibility of the straw. Chemicals that have been used to increase cell-wall degradation are broadly classified as acids, alkalis, or oxidative reagents (Garret and Dunbar [1992]). Alkali treatments, particularly treatments with some form of ammonia, are the most promising for improving the value of rice straw as a component in feedstocks. Ammoniation has both positive influences on the digestibility of rice straw (10-15 percent increase) and on the crude protein content of the straw (through the addition of nitrogen). Ammoniation can be accomplished by introducing ammonia into sealed, plastic covered stacks of loose or baled straw (Hart et al. [1975], and Sudstol et al. [1978]) or by applying anhydrous ammonia to rice straw as it is being baled in the field (Toenjes et al. [1986]. Ammoniation requirements are 4 to 5 kg per 100 kg of straw.

The increase in digestibility of rice straw due to ammoniation and the increase in feed intake that is likely to result can lead to significant improvements in animal response when the straw is fed in balanced diets containing at least 50 percent straw. In 72 percent straw diets fed to beef steers, ammoniated rice straw resulted in gains of .54 kg/day while untreated straw only resulted in gains of .23 kg/day (Garret et al. [1979]. In another experiment, diets of 50 percent rice straw recorded gains of .91 kg/day for ammoniated straw, and .71 kg/day for untreated rice straw (Han et al. [1989]. In diets of 36 percent rice straw, there were no significant differences between ammoniated and untreated straw in either digestibility or animal response.

Nutritionally, ammoniated rice straw is still inferior to alfalfa hay. The levels of crude protein, digestible energy, and metabolizable energy for ammoniated rice straw are about half of those for alfalfa hay (Garret and Dunbar [1992]).

Processors engaged in the ammoniation of rice straw need to take special precautions. There are reports that thermo-ammoniated rice straw (temperatures raised artificially to 80 - 90 degrees C) can produce toxic compounds. Cattle or sheep consuming toxic ammoniated straw show symptoms similar to the "crazy cow" disorder described in cattle consuming ammoniated molasses. The symptoms are hyper excitability, circling and convulsions. Animals may die from the disorder, some from injuries obtained while in the hyper excited state (Garret and Dunbar [1992]). There have been no cases of ammoniated roughage toxicosis due to the consumption of ammoniated rice straw in California. However, temperatures of 30-40 degrees C above ambient (common temperatures in California) have been reported under black plastic in the sun.

Economic Feasibility

In areas where higher quality feeds are readily available at competitive prices, the diversion of rice straw to feedstock will not be economically feasible. Garrett and Dunbar (1992) used computer-assisted least-cost rationing techniques based on ingredient prices of spring 1992 to evaluate untreated and ammoniated rice straw in comparison with other readily available roughages, concentrates and by-products feedstuffs. Their results are reported below.

For pregnant beef cows during the last trimester of pregnancy, Garrett and Dunbar found that the value of untreated rice straw was 45-55 percent of average quality alfalfa hay, and that the value of ammoniated rice straw was 60 -70 percent of alfalfa. For recently weaned 200 - 300 kg calves gaining .4 -.5 kg/day, untreated rice had 40 - 50 percent the value of alfalfa hay and ammoniated rice straw was valued a 55-65 percent of alfalfa. For feedlot steers weighing 300 kg and fed for near maximum gain (high energy diet only 10 - 15 percent roughage), untreated rice straw was worth about one third of average quality alfalfa and ammoniated rice straw was valued at 45 - 55 percent of alfalfa.

Given current market conditions, it is not reasonable to expect that rice straw will replace any of the more traditional livestock feedstuff.

Commercial Development

Although there continues to be some research on the use of rice straw as a component in livestock feed rations, the actual use of the product remains essentially static since the Report of the Advisory Committee on the Alternatives to Rice Straw Burning was issued in December of 1995.

Rice straw has been used successfully in livestock feed rations in at least two Sacramento Valley cattle operations. In one, protein supplemented rice "hay" is the primary source in winter months: in the other straw is a component of a complete ration. Grower experience suggests that properly cut, cured, baled, stored and supplemented rice residue has at least some value as cattle feed. The extent to which its palatability and digestibility can be manipulated by management is an important issue in determining its' value for feed, especially as the percentage of straw in the ration increases. Much of the previous research on using rice straw for feed purposes focused on improving the value of rice straw through various chemical and physical treatments. However, they did not distinguish between "rice straw" and "rice hay" and therefore may have overlooked some potential for pre- and post-harvest management to improve its' value. This is a topic for proposed research in 1997. An additional study taking place at the UC Imperial Ag Center is to test the effect of maceration on comparative feed value. This project started in the fall of 1996. Following is a more detailed description of a "rice hay" feeding operation that has been ongoing for approximately forty years.

Willow cattleman and rice grower Herb Holzapfel is convinced that rice straw can be valuable as cattle feed. Holzapfel Ranch runs about 500 fall calving Angus cattle in southern Glenn county and they have been routinely and successfully fed rice straw as the major part of the winter feed ration since the mid- 1940s. Mr. Holzapfel states that to be successful in preparing rice straw for cattle feed, it is necessary to treat is as hay, rather than a waste product to be salvaged. He starts the rakes one or two days after the rice is harvested and bales just as soon as the straw has cured. The goal is to preserve as much of the color, flavor and nutrients as possible. Experience has shown that the straw from short grain varieties seems to have more palatability, and higher nutritional values than that of other local varieties, and he currently prefers to make is "rice hay" from S 201 straw. The nutritional tests that have been performed routinely show crude protein values of 4% to 6%, with total digestible nutrients of 49% to 54%. The highest test result that Mr. Holzapfel recalls was a protein of 7.1% and a TDN of 54%. By supplementing rice straw with protein, minerals and salt, Holzapfels have a ration that can winter their herd for $38 per pair, a very economical figure. When asked what he felt that a cattleman could afford to pay for "rice hay", if he did not have access to it from his own fields, Holzapfel suggested that, in today's economy, perhaps $35 to $40 per ton delivered might be a valid number. He views the practice as a way to provide a low cost maintenance diet to the herd during the winter, and although it works well for them, the program may not be for everyone.

There is a feedlot operation in the Sacramento Valley that uses rice straw as a component in its' cattle feed ration. The feedlot specializes in finishing cattle for the Japanese market. However, as the "recipe" of the ration is a trade secret, it is difficult to assess its' potential impact on the consumption of rice straw, and we mention it only as a point of interest.

There are, however, a number of obstacles which hinder the use of rice straw as a major livestock food source in our area. The first of these is simple custom. Stock feeders prefer to use what they are accustomed to, what they have had success with, and what they view to be the most efficient and economic source of feed.

Mechanically, the process of baling and removing rice straw from the field can be substantially more difficult than for traditional hay crops. To be efficient, the fields must be drained early enough so that the soil can dry to the point that it can support the weight of the rice harvesting equipment, and then the baling and straw removal equipment. If the draining is done too late, or the winter rains come too early, and the fields are too soft or wet, then the process of raking, curing, baling, and removing the straw can become difficult and, in extreme cases, sometimes even impossible.

The timing of rice harvest also creates a problem in competition for hay equipment. Because this machinery is so specialized and expensive, the average rice farmer could not afford to equip his individual operation to do the job. Cooperative ownership is a possibility, but the window in which the rice straw must be removed from the field is very small, and scheduling would be exceptionally difficult, even under the most favorable of circumstances. The same scheduling problem would exist when working with contract operators. Most custom hay operators are already committed to getting the last cutting of hay off, and may be unwilling, or unable to give rice straw enough priority to allow it to be dependably removed from the fields before the winter rains begin. However, if a strong demand were to be developed for rice straw, there is sufficient volume of straw to be baled that it might become attractive for some custom operators to equip themselves to do this job specifically.

Another limitation may be the animals themselves. Mr. Holzapfel stated that the cows must be taught to eat the rice “hay”, that they do not chose it preferentially. In his operation, the older cows teach their young, but in a herd unaccustomed to rice straw, there may be a period during which they simply refuse to eat it. It is also possible that through forty years of careful culling and selection, Holzapfels may have built a herd that performs substantially better on rice straw ration than the average herd could be expected to do.

In the final analysis, it remains unknown as to whether the obstacles against using rice straw as a feed source could be easily overcome when more traditional livestock feeds remain readily, reliably, and economically available. It seems unlikely, however, that an increase in the commercial use of rice straw as livestock feed sufficient to have a major effect on the disappearance of California rice straw will be seen in the immediate future.

Potential for Rice straw Diversion to Cattle Feed

The potential of the feedstuff market to absorb increasing amounts of rice straw is very small. Though it is possible to feed rice straw to livestock, rice straw is an inferior component in livestock feed (even when treated), and it is unlikely that stock feeders will be willing to accept such an alternative.

Recommendations Concerning Livestock Feed

The Advisory Committee does not have any recommendations concerning the use of rice straw as a component in livestock feed in that this is not currently a viable option.

F. RICE STRAW COLLECTION AND MARKETING

All of the alternatives for diverting rice straw in the Energy, Manufacturing and Construction, Composting and Soil Amendment, Animal and Human Food and Bedding, and Environmental Mitigation categories require the collection, removal, and typically the storage of the rice straw. An important element in determining the viability of any of these options is the technological constraints inherent in the collection and removal process and the costs involved in the collection, removal, processing and storage of the straw. For many of the alternatives considered by the various subcommittees, the arrangements for collection, removal, transportation and storage of the rice straw might be incorporated in the processing package offered by the alternative industry. However, for many of the alternatives, the size of the operation prohibits investment in collection services. For both the larger potential users of rice straw and for the smaller users, establishing an efficient marketing mechanism for rice straw will make rice straw a more attractive input. In fact, in the absence of an efficient marketing mechanism, the diversion of rice straw to any of the off farm alternatives could be severely constrained.

Because these marketing considerations could play a crucial part in the success of many of the off farm alternatives, the "business" of straw removal and marketing needs to be examined. As with the subcommittee reports, the technological process and constraints, economic feasibility, commercial development and potential capacity of the industry is examined, and recommendations to aid the establishment of the industry are formulated.

Technological Process and Constraints

Collecting rice straw is limited by the timing of the rice harvesting and the weather. Harvesting of rice in the Sacramento Valley typically begins during August and culminates in November, when excessive rain keeps equipment from entering a rice field. Rice that is harvested late in the fall after heavy rains, tend to rut up the fields and make straw removal almost impossible until the ground dries enough to allow collection equipment to operate. Late rains during the 1994/95 winter caused an undesirable delay in the replanting of some fields as late as June.

A number of alternative rice straw collection methods have been tried, with the most effective being to bale and roadside the rice straw as soon after rice harvest as possible. Estimated costs for baling and road siding rice straw vary from $17 to $25 per ton which corresponds to $51 to $75 per acre. Moss et al. (1993) in the "Foster Report," estimate that the least-cost options of the various straw removal methods result in a narrow cost range of $19.20 to $19.60 for baling and road siding a ton of straw (costs are based on 80 to 110 pound bales).

Transportation of baled rice straw will vary with the distances to potential end users. It can also vary with the volume of rice straw carried in each truckload. Depending on the type of trailers and whether the bales are large and rectangular, small and rectangular or large and round, the weight per truckload ranges from 15 to 24 tons. Moss et al. (1993) present estimates in the "Foster Report" for trucking costs (based on California Public Utilities Commission's Minimum Rate Tariffs for June 12, 1982 which were used as guideline by haulers). Table A-3 from the "Foster Report" is summarized below in Table IV.

Table IV
Transportation Cost Estimates.

Load size:	**15 tons**	**20 tons**
Trip Miles: 0 to 3 miles	41¢ / ton ÷3=13¢ /ton/mile	27¢ / ton ÷3=9¢ /ton/mile
45 to 50 miles	73¢ / ton ÷50=1.5¢ /ton/mile	51¢ / ton ÷50=1¢ /ton/mile

If end-use processing cannot be synchronized with harvesting, the rice straw will need to be stored. Storage of sufficient quantity could add substantially to the cost of the production process. At a minimum, storage costs could add about 5 to 20 cents per cwt to processing costs (Moss et al. [1993]).

In comparison with other straw, rice straw is a particularly difficult commodity to collect, transport and store. Three observations support this assertion. First, the high silica content of rice straw makes any "machining" of the straw (such as cutting, collecting, baling, etc.) more costly. The abrasive nature of rice straw imposes extra wear and tear on machinery and equipment. Second, the sheer bulk of rice straw production makes it a costly commodity to collect, transport and store. Third, in cases of late harvesting and early rains, rice acreage is particularly wet and boggy. This could lead to soil damage and rutting if heavy machinery is hauled over the wet fields. Wheel ruts from harvesting in wet fields will also make it difficult to remove or closely chop the straw (Moss et al. [1993]).

Economic Feasibility

The economic feasibility of rice straw marketing is determined by the demand for rice straw. Currently the market is rather small but with the rice straw-burning phase down and the on-going efforts to establish alternative uses, it is hoped that the market will increase.

Commercial Development

Two commercial marketing operations were identified by the Subcommittee on Composting and Soil Amendment. The most established commercial market operation for rice straw marketing that the subcommittee documented is R. S. Construction Specialty in Willows. Through the Willows operation, Rick Green supplies rice straw to building industries and erosion control. He is currently investigating the possibility of supplying mushroom cultivation. He has applied for a federal grant to produce improved straw handling equipment in order to obtain straw in the quality he needs for the full range of straw uses.

Currently, Green believes average straw can be baled and stacked for about $1 per bale or $75 per acre (80 lbs per bale corresponds to 75 bales per acre). He also allows for $0.25 per bale in storage. He believes that by 1998 he may be able to handle up to 70,000 tons of rice straw (23,300 acres), but does not see his usage growing significantly beyond that production. However, Green is out of rice straw for this season and has had to turn buyers away. He is actively pursuing growers to supply straw for the 1995 growing season.

Another commercial rice straw marketing operation is headed by Gene Fenn, a rice and hay producer in Butte County. Fenn has baled rice straw for several years. His costs also run approximately $1 per bale or $75 per acre (80 lbs per bale corresponds to 75 bales per acre) for baling, with storage and transportation additional. He is not able to sell rice bales with any consistency and has to "dump" or hold it for excessive periods of time. Consequently, he sells most of his rice straw bales for $3 - $3.5 per bale to small users who come pick them up at his location. At this time he does not see significant potential in rice straw compared to his other hay products.

Recommendations Concerning Rice Collection and Marketing

The Air Resources Board, Department of Food and Agriculture, and the California Energy Commission should undertake jointly funded research efforts with the Rice Research Board to improve the economics of collection, transportation and storage of rice straw in preparation for diversion to off-field markets.

II. ON FARM ALTERNATIVES

A. REPORT OF THE SUBCOMMITTEE ON CULTURAL PRACTICES

The primary non-burn alternative continues to be soil incorporation. The report of the Subcommittee on Cultural Practices examines the current cultural practices used by growers, technical constraints and economic feasibility of rice straw incorporation, and the over-all potential for soil incorporation to divert rice straw.

Technological Process and Constraints

As practiced in the Sacramento Valley, rice straw incorporation entails leaving the straw in the field, providing some degree of soil-straw contact utilizing various chopping, tillage and rolling implements, then using the soil's environment to decompose the straw. Soil incorporation practices are best done in the fall, immediately after the rice harvest is complete. The normal harvest period for most rice in the Sacramento Valley is from September 15 to October 30, peaking about the first two weeks of October. Depending on weather, harvest may begin as early as late August and continue into December; consequently, the time of incorporation varies accordingly. Data from Williams, et. al. (1996) suggest that growers recognize the importance of starting early because the mean start date for soil incorporation in their survey advanced from the third week in November in the 1993-94 season to the first week of November in the 1995-96 season. Some growers start immediately after harvest of each field, while others, for reasons concerning labor and management, wait until all fields are harvested. In some systems, additional work may be done during winter months. Early fall rain may preclude fall incorporation until dry periods in the winter or spring, as in 1994-95. As the phase down proceeds, the amount of spring incorporation is likely to increase because of insufficient time to complete the work in the fall. This possibility is important because the potential for straw-related crop problems increases with spring incorporation.

A number of factors have conditioned the development of rice straw incorporation systems in the Sacramento Valley. First, California rice fields produce large quantities of coarse straw. Nearly 99% of California rice is planted to semi-dwarf cultivars (Brandon [1995]), and at nitrogen (N) fertilizer rates which optimize yield, these cultivars produce an average of 7110 lbs/acre (3.6 tons/acre) of straw (Roberts et al.[1993]). High rates of nitrogen fertilizer (> 150 lbs N/acre) can increase straw production to as much as 9000 lbs/acre. Rice straw also has a high silica (8.8-13.3%) and fiber (56.3-68.9%) content [Fadel, 1994], making it more difficult to handle and more abrasive on equipment than other grain straws. This large volume of coarse material requires much energy and heavy equipment to incorporate it.

The second major conditioning factor is the process of straw decomposition itself. Interactions of nutrients, microorganisms, moisture, temperature, and oxygen supply drive the decomposition process (Brandon et al. [1995]). Quantity and quality of the straw, nitrogen content, straw particle size, time and method of incorporation, crop and soil management practices and crop rotations are also important in determining decomposition rates (Mikkelsen & Broadbent, 1981). Williams, Goldman-Smith, et al. (1996), found that soil and management factors associated with straw decomposition include the number of years of incorporation, soil texture and duration of the incorporation period. In some systems, number of tillage operations was also correlated with rate of decomposition. In the same study, temperature and moisture regime were cited at the primary determinants of rice straw decomposition. Given the timing of rice straw incorporation and decomposition (i.e., during the wet, cold months), rice straw may not always have time to adequately decompose under the conditions found in the Sacramento Valley. Consequently, growers will likely have increasing amounts of work to do in the spring of dry and/or cool years to dispose of remaining straw.

The third conditioning factor is that most rice is grown on poorly-drained soils which have fine texture and/or shallow hardpan. In a study on the future of the California rice industry, Coppock (1994), stated that 600,000 acres of Sacramento Valley soil, much of which is used for rice, is either heavy clay or hardpan. Fine textured soils are physically more difficult to manipulate compared to coarser texture soils, presenting unique soil incorporation problems (Williams et al. [1995]). As a result, the energy, equipment and labor costs associated with soil incorporation of rice straw are greater than they might be on less challenging soils. Furthermore, the poor internal drainage characteristics of many rice soils limit the choice of alternative crops, thereby enforcing more-or-less continuous rice cropping. Crop rotation, as a means to alleviating straw disposal problems, is therefore, not available to much of the California rice industry. Those producers who can take advantage of rotational sequences have experienced fewer straw-related problems.

Two major rice straw incorporation systems have emerged (Brandon et al [1995] and Williams et al [1995], differentiated by water management. These two systems are first discussed in the context of fields under continuous rice production. This is followed by the discussion of straw management in a rotational system.

The first major rice straw incorporation system is a **rainfed** method which depends on stored soil water and winter rainfall for moisture. Various tillage implements are used to physically mix the straw into the soil where it is exposed to decomposing organisms in an environment that is largely aerated. A wide array of choppers, stubble discs, plows, chisels and corrugated rollers are used in many combinations. The exact sequence, type and number of operations varies with the individual grower. A typical program might include flail chopping after harvest, followed by stubble discing one or two times. The field then remains idle throughout the winter and is conventionally prepared in spring for planting. Those growers who do not have access to winter water, or because they prefer not to flood, use nonflooded systems of soil incorporation. As the phase down progresses and the need for fall straw work increases, the burden will fall heaviest on those growers using nonflood methods of straw management. This method usually takes more time, must be done in dry conditions, and appears to be less effective. Growers farming in heavier soils (clays) will have additional difficulty because of the greater power requirement to mix straw in these soils

A variation on this theme has emerged, wherein irrigation water is applied in the fall, but not retained as a flood. The irrigation water ensures that decomposition is not limited by available moisture, as in the rainfed system. It may be a choice where flood water is unavailable throughout the winter or too costly to purchase. Another variation is that many growers capture rainfall in their fields and hold this water, creating a kind of irrigation or temporary ponding.

The second system uses **winter flooding** as the principal decomposing method. Shortly after harvest, flood water is returned to the field and retained throughout the winter period. The water is drained about March 1 to allow the field to dry for seedbed preparation. Straw may be chopped, disced, chiseled or rototilled prior to flooding. Alternatively, the straw may be rolled after flooding with specially developed, open-faced rollers that either press the straw onto the soil surface or achieve some soil-straw mixing. Such fields may or may not be chopped. Again, the exact sequence, type and number of operations varies with the individual grower. In winter flooded fields that were not soil incorporated, the remaining straw often lies as a blanket over the soil following drainage, keeping the soil wet, which may delay field access for several days (Williams et al. [1995]).

Winter flooding for straw decomposition is a relatively new technique which arose from grower innovation and only recently is being evaluated through controlled research studies. Data on commercial rice fields for three years, 1993/94-1995/96, (from Williams et al. [1996]) suggests that winter-flooding decomposes straw faster than rainfed or irrigated systems. Furthermore, this system requires less energy and time to do than other methods, and is more flexible in that rainfall does not necessarily impede the process. It is, therefore, more popular than other methods.. No public record is available for determining the acreage of winter flooded rice fields, thus information must be gathered from other sources. Data developed by DWR, based on information supplied by water purveyors, shows that during the 1994/95 winter period, 123,220 acres of rice were flooded [Charles Ferchaud, personal communication, 3/97]. This figure does not differentiate fields flooded for straw decomposition and fields flooded for duck hunting. The same source estimated flooded acres in 1995/96 at 150,000 acres, although a similar survey was not undertaken. Winter flooding now predominates and is used by more rice growers than other systems.

Despite the widespread satisfaction with winter flooding, numerous questions remain requiring long-term research about soil and crop effects. Of major interest is what happens to physio-chemistry when the soil remains wet nearly year-round; what happens to crop nutrients; how are disease incidence, severity and type affected and what are the cumulative effects on rice production; and what are the environmental impacts of winter flooding, including the effect of methane generation from anaerobic decomposition of rice straw. Long term studies at two locations are now addressing these issues.

Winter flooding has been heavily promoted by waterfowl groups as the best approach to straw management. Several studies have shown that winter flooded rice fields are an important source of carbohydrates, including rice and weed seeds, and edible invertebrates. For example, Miller, et. al. [1989] found that up to 300 pounds of rice grain remain in a typical field after harvest. However, specific straw and water management practices, such as rolling and winter flooding, can affect results. For example, Loughman and Batzer [1992], found that flooded burned fields had the highest densities of edible invertebrates, rolled fields had the lowest level, and unrolled and flooded fields were intermediate, although, invertebrates increased in non-burned fields in late winter. Rice and weed seed densities were greater in non-burned fields. The authors cited concern about the need to increase invertebrate production for ducks in non-burned fields.

Whether or not waterfowl populations are increasing because of the additional acres of flooded fields is currently speculative because so many external factors determine their numbers. However, this practice has proven beneficial for the image of the California rice industry. Furthermore, a study by Pettygrove, et. al, [1996], showed that the presence of waterfowl can contribute substantially to decomposition of rice straw during the course of their foraging activity. These synergisms between the needs of rice producers to dispose of straw and the potential benefits to waterfowl promise to keep winter flooding in the forefront as the system most used by rice growers.

Despite the advantages of winter flooding it is not readily available to all farmers. Those growers in areas serviced by pumps or where surface water is unavailable in winter or too costly, must use other methods. Until recently, most water districts in the Sacramento Valley were averse to delivering water during the winter months because they wanted off-season access to their canals for maintenance. Management of winter water also entails additional cost to the water district. However, many purveyors now deliver at least some water in the winter to satisfy the demand, although this is causing them to re-evaluate their policies in respect to canal maintenance and the added costs associated with this new use.

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Potential Consequences of Rice straw Incorporation

Extensive soil incorporation of rice straw could have an impact on several aspects of rice-crop productivity. Research findings and empirical evidence concerning soil-quality and disease effects on crop productivity is presented below.

Mikkelsen (1993) described several potential consequences of winter flooding to a growing rice crop and rotation crops. These consequences include greater emphasis on soil aeration and drying in the spring; net loss of soil N and probable increase in fertilizer N requirement; more difficult seedbed preparation; decreased availability of zinc and increased availability of phosphorus for the rice crop; decreased availability of phosphorus for rotation crops; formation of a variety of decomposition products, including organic acids, alcohols, and various gases, which may be toxic to rice, and increased algal blooms in the growing crop.

Rice straw interacts with **nitrogen** management in the growing crop. Williams et al. (1968) showed that the nitrogen content of the rice straw is critical in determining if the crop yield will be affected. Rice straw at .54% total N or higher will not compete with the crop for soil nitrogen. In an eight year study, Williams et al. compared burned vs. incorporated straw at several N rates and concluded that "under flooded conditions, nitrogen tie-up need not be a problem" when rice straw is incorporated. Subsequent research by Pettygrove et al. (1995) in a five year study found that fall-incorporated plots needed slightly more nitrogen fertilizer for maximum yield than fall-burned plots. Spring incorporated plots gave similar yield as fall burning and required similar N rates, suggesting that immobilization of fertilizer N was not a problem. The additional N requirement of fall-incorporated plots was attributed to the higher yield. Mikkelsen and Broadbent (1981) observed that burning removes nitrogen and sulfur, while removal of straw removes nitrogen, sulfur and other mineral elements contained in the straw. Soil incorporation recycles all of them, but variable amounts of non-mineral elements are lost through decomposition.

Zinc and iron deficiencies are most often associated with alkaline soils. With shallow tillage, typical of most rice fields, the chemistry in the plow layer remains adequate for good rice production. But, when growers till deeply, as is sometimes done for straw incorporation, micronutrient deficiencies have been observed when alkaline subsoils are brought to the surface (Williams [1994], personal observation).

Blooms of filamentous **algae** can impede the growth of young rice plants. Any readily available source of nutrients, including inadequately decomposed organic matter is suitable for algae and potentially contributes to algal blooms (Flint [1993]). Williams et al. (1995) however, did not observe a direct relationship of algal blooms and straw incorporation. They cited other complicating factors such as water quality and fertilizer practices which also contribute nutrients to the system, resulting in algal blooms. Rice straw in the spring is partially decomposed and has little nutritional value to support algal growth. The 1996 crop season produced one of the worst algal blooms in history of the California rice industry. A combination of late planting because of May rain, wet seedbeds, and high temperatures in late May and early June provided the necessary environment. The role of straw, however, is unclear. No research was reviewed that specifically links straw incorporation and algal blooms in rice fields, although some growers have indicated this is a problem.

Anaerobic decomposition of rice straw results in an increase of **toxic products** that potentially can damage the rice crop. They include volatile fatty acids, hydrogen sulfide and methane (Watanabe [1984]). Effects of **volatile fatty acids** are particularly acute at lower pH, with root elongation being most sensitive. As a result, nutrient uptake can be impaired (Yoshida [1981]). Several researchers, reported in Cannel and Lynch (1984), have described the evolution of volatile fatty acids, such as formic, acetic, propionic and butyric acids from decomposing organic matter and their adverse effects on rice roots. However, the toxic effects of these organic acids may vary because humic substances, such as decaying rice straw, may absorb them, depending on amount and type.

Under highly reduced, flooded conditions, sulfate sulfur is converted to sulfide sulfur, which will react with iron to form a harmless compound, or, in soils with low active (ferrous) iron, will form toxic **hydrogen sulfide** (Patrick and Reddy [1978]). Decaying organic matter intensifies reduction, enhancing the conditions that produce hydrogen sulfide. Injury is most common on lighter texture soils relatively high in organic matter, but also occurs on fine texture soils (Flint [1993]).

Methane may be formed when a readily decomposable source of fresh organic matter, such as vetch or rye grass, is present. Several studies, reported in Lauren et al. (1993), showed that rice straw doubles emission of methane from flooded rice by providing a readily available substrate of carbon for methanogenic bacteria. During winter flooding this methane is a matter of environmental concern since it is a greenhouse gas. In addition, methane is potentially toxic to rice when it occurs during the growing season. Experience of growers in 1994 (Williams et al. [1995]) suggests that most fields with incorporated straw had evidence of gas formation, as detected by copious bubbling. This was not measured quantitatively. In fact, most burned fields bubble to some extent because they have decaying organic matter in the form of unburned stems and plant roots. The only plant damage observed was where high amounts of rice straw accumulated, such as in corners and along field edges. Lauren et al. (1994) found that methane flux in a planted rice field in California increased with purple vetch (a readily decomposable winter legume) incorporation, more than it did with rice straw only. Plots with vetch only or vetch plus spring incorporated straw, produced 1.5 to 1.8 times more methane than plots with straw only incorporated in the spring or fall burned plots without vetch. Growers have not been reporting an increase in gas problems and it is possible that fall incorporation, which reduces the volume of straw more than spring incorporation, is abating the problem. Preliminary data (Hill and Fitzgerald, [1997]) showed two peaks of methane production, winter during flooding and summer during cropping, both of which were associated with the quantity of straw. Gas production might be more of a crop problem in spring incorporated fields where volumes are likely to be higher.

The most serious adverse crop effect of rice straw management, and the one that is most likely to occur, is an increased in diseases. Two major rice **diseases** that are affected by straw management practices are prevalent in California: stem rot (*Sclerotium oryzae*), and aggregate sheath spot (*Rhizoctonia oryzae-sativae*). These diseases have different effects on the crop, but both are considered economically important diseases of rice in California.

Both diseases produce sclerotia which live in rice straw and soil, and survive over the winter. When fields are planted the next spring, these sclerotia float to the water surface, lie against rice stems, germinate and infect the new crop. These diseases complete only one life cycle per year in the rice field, beginning in the spring with overwintered sclerotia and ending in the fall with the next overwintering generation. The population of stemrot sclerotia in the soil is linearly correlated, up to 0.6 sclerotia/gram of soil (Bocus & Webster [1979]), with disease severity the next season. In this sense, the population of sclerotia partly determine the level of disease, at least in the linear portion of the relationship. Because the straw is the primary reservoir of inoculum, straw management is very important in determining the severity of these diseases.

Several studies have evaluated the relationship of straw management on the incidence and damage of stem rot. In a summary of rice disease work prior to 1980, Webster and Wick (1981) concluded that

> ...open-field burning is an invaluable form of stem rot disease control in the California rice-cropping system....incorporation of residue....resulted in increases in *S. oryzae* inoculum and stem rot disease severity and reductions in yield....complete removal of residue is a more satisfactory

alternative than soil incorporation if open-field burning cannot be continued. (pages 23 -24)

In two studies, one for four years and the other for five, "inoculum levels increased significantly with each subsequent year of residue incorporation" (Webster and Wick [1981]). Disease levels also increased, resulting in lower rice yields. In a recent five year study by Pettygrove et al. (1995), disease levels were higher in incorporated plots than in burned plots, although yield did not reflect this. In addition, in a parallel study at the same site, sclerotia numbers and their survival corresponded to straw management, suggesting a potentially higher disease severity level in straw plots than in burned plots (as reported in Webster et al. [1995]). In these studies, as in others, stem rot was more severe at higher fertilizer N rates, and aggregate sheath spot was more severe at the lower N rates. Recent evidence [Williams , et.al. (1996)] suggests that stem diseases are increasing in fields with repeated straw incorporation. They found that stemrot severity and aggregate sheathspot incidence   increased from 1994 to 1996 in commercial fields with straw incorporated each year.   At a long term rice straw management site burning residue reduced the number of viable stemrot sclerotia, while they remained nearly the same in other treatments (incorporation, rolled, removed, each with or without flooding).   At a second site with similar treatments, sclerotia levels rose in all treatments, raising questions about the role of soil characteristics on disease. [Webster, et.al. (1996)]

In the fall of 1996, a new disease in California, rice blast, *Pyricularia grisea*, was identified in 33 fields in Glenn and Colusa Counties of 508 which were examined [Scardaci, et.al. (1997)]. This disease, which occurs in 85 rice producing countries worldwide, can be highly destructive. It is a very different disease from stemrot and aggregate sheathspot. Unlike the other two diseases, blast can have multiple disease cycles, as frequently as once per week under ideal conditions, producing spore showers which can infect previously uninfected fields. Stemrot and aggregate sheathspot infect mainly the fields in which the inoculum occurs, but blast spreads on the wind. The role of burning in management of blast is therefore different. Straw and stubble are the primary overwintering sources of inoculum and to a small extent, seed and possibly host weeds. Destruction of diseased crop residues by burning is a recommended management tool to reduce the inoculum in an infected field. However, this will not protect the subsequent rice crop from infection by windblown spores from other fields. Hence, individual field burning is not likely to be as effective for controlling blast compared to its role in controlling stemrot and aggregate sheathspot. Burning on a regional basis in infected areas would provide more protection [RK Webster, reported to Feb. 24, 1997 meeting of the Rice Disease Management Committee]. In 1996, all the confirmed fields were burned in addition to fields adjacent to them, for a total of about 12,000 acres. This was done under the “act of God” provision of the AB 1378. The purpose was to reduce, as much as possible, straw borne sources of inoculum. Eradication efforts were not undertaken, however. No local experience or information is available regarding the role of straw removal in controlling blast; however, it is probable that removal would provide some reduction of overwintering inoculum. However, the fields would not be protected from airborne infection the next season. The 1996 outbreak was probably directly related to unusually warm, humid and calm weather, which is not typical of the Sacramento Valley. A return to more typical arid conditions argues against blast recurring. But, whether or not blast will persist in California is unknown.

Current disease management practices rely entirely on cultural methods, including burning, crop rotation, tillage, and optimal fertilizer, seed rate and herbicide application practices (Flint [1993]). There are no fungicides registered for stem disease control which can be sprayed on rice fields in California, and no fungicide work had been done for many years, until 1996, when field studies on two products were initiated [Webster, et al. (1996)]. Stimulated by the rise in disease levels and occurrence of blast, DuPont considered then declined California registration of BenlateJ for control of blast and aggregate sheathspot (but not stemrot), via a third party 24c registration process. Benlate is used in the Southern US rice area for control of blast and Rhizoctonia sheathspot (which does not occur in California). We have no experience in California with this material on rice in commercial fields and little experimental work has been done recently. Zeneca is experimenting with QuadrisJ is one of the first fungicides in a class of compounds based on naturally occurring chemicals.[Zeneca Ag Products technical information bulletin, undated] It has broad spectrum disease control on vegetables and small grains, and was first field tested in California in 1996. However, new EPA rules relating to food crop residues are currently slowing down the registration process of all new products, so it is uncertain when it will be commercially available. Quadris has shown potential for control of several rice diseases, including blast and stemrot. Much needs to be learned before definitive statements can be made regarding its potential in California rice.

Resistance to stemrot and aggregate sheathspot is slowly being incorporated into agronomically suitable varieties, but "progress has been slow and difficult" (Brandon [1995] page 3). In 1996, 158 crosses were made to transfer stemrot resistance from *Oryzae rufipogon,* and 19 crosses from other species of rice, producing 6137 head rows for evaluation. [Oster, (1997)] Only a fraction of a percent showed improved resistance. Several molecular markers have been found that can differentiate resistant parents, but their full value as not been determined. Progress on aggregate sheathspot resistance has also been slow, with fewer than 4% showing improved resistance. The best selections appear to be also more resistant to stemrot. Current cultivars used in California are very susceptible to the race of blast which occurred in 1996, and development of stable resistance is highly challenging; but, worldwide, resistance is considered the primary means of blast control.

The legislation governing reduction of burning provides for up to 25% "conditional" burning of an individual grower's rice after full phase down is achieved. The provision requires the Agricultural Commissioner to determine "the significant presence of a pathogen in the field in an amount to constitute a rice disease such as stem rot..........caused a significant, quantifiable reduction in yield." Growers would not be allowed to trade this conditional permit. The law did not say exactly how the determination to burn is to be accomplished, so a committee is now working on the issue. Within the confines of the current law, a biologically based system that requires analysis of each field will probably be devised, but clearly will be time consuming and expensive. Growers are concerned that the conditional burn permit is dependent on the disease causing damage before burning can be allowed, which is not conducive to good crop management. It has been widely suggested, based on an original idea forwarded by UCD Agricultural Economists Richard Howitt and Daniel Sumner, that burn permit trading would greatly facilitate and cheapen the public's cost of conditional burning. By allowing trading of some percent of burnable acres, growers could allocate the acreage themselves via a permit trading market. In this way, a grower who needed to burn more might be able to buy acreage from one who did not need to burn. Such a system would require amending the current law.

Crop Rotation

The benefits of rotation with respect to rice straw management include breaking pest cycles, relief from scheduling pressures, allocating costs to higher value crops, lower rice production costs and higher rice yields. Nevertheless, a high percentage of the rice produced in California is grown without rotation because of soil constraints. It is commonly estimated that more than half of California rice acreage is in continuous production. Many fields have been planted annually for ten to twenty years, some longer, with the only break for land leveling.

Soil characteristics of many rice fields--fine texture, shallow, hardpan, claypan, or combinations of these--severely limit economic crop choices and rotation possibilities. Coppock (1994) portrays three general categories of rice soils: those in continuous rice production; those with limited rotation choices, such as winter cereals, sugar beets, and low yield safflower; and, those with a wider choice of rotation crops, such as processing tomatoes, oilseeds, winter cereals, dry beans, feed grains, sugar beets and cucurbit crops. Cotton is currently grown on a small acreage in the Sacramento Valley, with a few of these fields former rice fields. Its role as a rice rotation crop and potential for acreage increase in the Sacramento Valley is unknown. Only in this latter category is any real rotation practiced, wherein rice becomes the secondary crop in an economy typically driven by processing tomatoes or other higher value crop. The sequence in this rotation typically includes only one or two years of rice cultivation before a rotation crop is grown. The geographic areas where this type of rotation is practiced include the Sutter Basin, some of District 108 in Colusa County, and a small area west of I-5 in Colusa Co. The balance of the rice land farmed in the Sacramento Valley falls into the other two categories of which "rice only" is the largest. Regular rotational sequences on most of the land in the middle category do not really exist. Market forces and/or water supply may persuade a grower to plant wheat or safflower instead of rice in the occasional year. On the rice-only land, when it is not advisable to plant rice, the land normally lies idle. Formerly, the federal farm program was a big determinant in whether or not to plant rice, but changes in the program in 1996 have changed its influence in rice cropping decisions. A more complete discussion follows in the economic section.

Typically, those rice fields that are in continuous production have the highest levels of stem rot and aggregate sheath spot, and those in rotation have lower disease levels. The calculated half-life of stem rot sclerotia in field soil, with or without rice straw residue, is 1.9 years (Bocus and Webster [1979]), which suggests that a single year rotation out of rice will be helpful but may be insufficient to adequately lower sclerotia below the economic threshold in a serious disease situation. Regular rotation, every other year, would be more effective. Rice straw incorporation in rotation fields is not likely to increase disease levels, while it is likely to increase in rice fields in continuous production. In addition, soil fertility levels may be higher in rotated fields because of the longer dry period which increases levels of mineralizable N. Per unit production costs may go down because fewer pesticides and lower fertilizer rates may be needed, and yields are typically higher. Fields in rotation are typically the better soils and rice yields respond accordingly.

As previously noted, fall straw management may be severely constrained by weather. Rotation does not necessarily change this situation, but it may help in some situations. For example, if the rotation crop can be planted in May or June, as is the case with cucurbits or dry beans, planting can be scheduled to allow for more "relaxed" straw management. However, this is not true for processing tomatoes, wheat, or safflower, all or which require fall ground work and are under the same time constraints as rice. Straw in the seedbed of these crops may be problematic.

By growing a higher value crop following rice, the cost of straw management may be partially borne by the next crop which may more easily afford it without jeopardizing profitability. However, the seedbed requirements for rotation crops are usually more demanding than for rice, so that disposing of straw usually requires more work and expense than it does for rice.

Rice straw management is generally less troublesome in a rotation system compared to management in a continuous rice system. Unfortunately, rotation is currently available only in a limited area. The vast majority of rice fields are dedicated to rice production only, by virtue of either soil characteristics and/or land forming appropriate for rice but not other crops. Only major investment in land re-leveling and equipment, innovative cropping methods and unique crop introductions suited to poorly drained soils would change this picture. Consequently, the rice producers who farm this “rice-only” land are the ones who are most concerned about the consequences of the phase down as it affects their ability to successfully respond and stay in business.

Effect of Rice straw on Grain Yield

Attempts to observe the effects of rice straw incorporation on **grain yield** have produced mixed results. In an eight year study at the Rice Experiment Station, Williams et al. [1968]), found no difference in grain yield between burning and soil incorporation at any of several nitrogen levels. Diseases were mentioned but not evaluated in this study. Brandon et al. (1970), found that soil incorporation of three tons/acre of rice straw at 0.6% N content significantly reduced rice yields. Yield loss was attributed to nitrogen immobilization and formation of toxic decomposition products. Multi-year studies summarized in Webster (1980), linking disease severity with increases in inoculum level due to straw incorporation, found that yields were reduced an average of 9.2% compared to burning. The authors also noted increased costs associated with straw incorporation, and that burning prevented the buildup of disease where it was not a problem. Disease control experiments using chemical fungicides demonstrated yield gains from 9 to 24% above that which was gained from burning. Only stem rot was present in these studies. Pettygrove et al. (1995), found that for five seasons, the yield of fall-incorporated plots averaged 5 cwt/acre higher than that of fall-burned or spring-incorporated plots. In this study, both stem rot and aggregate sheath spot were present. Severity ratings for both diseases were related to straw treatments only in the fifth year. This suggests that, over time and with continuous incorporation, disease severity would increase in the incorporated plots with a possible reduction in yield.

Limited data in Williams et al. (1995), suggests that in a single year, rice straw incorporation did not reduce average grain yields in commercial fields, compared to the previous year when straw was burned. However, some growers did report straw related yield reduction in individual fields. Straw incorporation did not generally reduce **plant population,** except where rice flood water and wind accumulated dense mats of straw. In one field, the loss of production area was estimated at 1%. However, in a 1993/94 UC research site in Maxwell, winter flood treatments had early stand establishment problems, probably related to generally wetter seedbed (Scardaci

[1995] personal communication). No growers using winter-flooding reported similar problems in commercial fields (Williams et al. [1995]).

Two long term rice straw management experiments, near Maxwell beginning in 1994 and near the Rice Experiment Station (Biggs) beginning in 1995, are underway [Hill, et.al. (1996), in press]. Treatments include burning, incorporation, rolling and removing, each with and without winter flooding. Results to date suggest no yield trends associated with straw management or years. However, in individual years, certain treatments differed. At the Biggs site, removal of straw resulted in lower grain yields the following year. This was subsequently found to be related to potassium deficiency in the soil and removal of nutrient potassium in the straw, thus identifying a potential crop problem associated with straw removal. Burning and incorporation leave the potassium in the field. At the Maxwell site, flooded treatments yielded more than non-flooded treatments in 1995, but not in 1994 or 1996, or in either of the two years at Biggs. Researchers related differences in treatments to variation in herbicide injury, organic acid production, weeds and diseases.

In a summary of a three year study of commercial fields, all with straw incorporation, [Williams , et.al. (1996)] researchers were unable to detect a large general yield reduction in California rice fields that was clearly attributable to straw management. But, they noted that many growers are experiencing increased disease related to their straw management practices, and this is contributing to yield reductions experienced in the 1995 and 1996 seasons. They went on to say, “To what extent low yields the last two seasons are a direct effect of straw is a matter of conjecture. “ Other factors impacting yields were adverse weather (causing wet seedbeds, late planting, panicle sterility), poor weed control and herbicide injury.

Economic Feasibility

Two recent studies have evaluated the costs associated with rice straw management. The first, by Blank et al. (1993), used a sample cost method, wherein several straw management scenarios were analyzed using a standardized cost set. Per acre costs to soil incorporate rice straw in this analysis ranged from $12.04 to $80.60/acre, depending on the system used. Low costs were associated with minimal operations, such as combine mounted choppers and a single pass with a stubble disc. High costs were associated with use of a self-propelled forage chopper and multiple tillage operations. Water costs for winter flooding were not included, although cost of rolling flooded rice was calculated.

In the second study, by Williams & Goldman, (1997), case studies were done of 83 rice straw incorporation systems throughout the Sacramento Valley from 1994 to 1996. Data on farmed acreage, rice acreage, equipment usage, age, purchase price, operation speed, labor rates, custom rates, water cost, and other inputs, were gathered in an interview. The data were then tabulated for each farm. Because each case was unique, costs of doing the same operation varied widely among farms. Total costs ranged from less than $7.70/ac to a high of $76.54/ac, and a mean of $36.31/acre. Sixty percent were in a range of $18-48/ac. The average cost for winter flooded fields was $36.36/acre (including water) $33.37 for rainfed fields, and $46.01/acre for irrigated fields. Costs did not differ greatly across years. The higher costs were associated with use of expensive custom operations, manure, and additional spring groundwork, which averaged $4.43/ac across all fields. Water costs in flooded and irrigated systems averaged $9.96 and $9.22/ac, respectively.

These analyses included the direct cost of fall operations plus additional straw-related expense needed to prepare the field for planting, including increased fertilizer costs. Twenty seven percent of cooperators in the study said they incurred additional expense in the spring, more of them in the first year when straw decomposition was not as complete. Whether or not a field required extra expense in the spring was unrelated to the straw management method used. Yield loss or gain were not included in this analysis. No study of indirect costs has yet been made because of the difficulty of directly linking straw management practices with changes in inputs and yields.

Straw management costs are an expense with no direct offsetting income from the activity. In a scenario of low price and low yield, the industry could very easily shift from profitability to substantial loss, with spin-off effects in the entire agricultural sector. This situation has in fact occurred as low average yields from the 1996 crop and low market prices are resulting in net losses for many farmers. The 1995 farm bill created major changes in the income from rice subsidies. Beginning in 1996, subsidies are greatly reduced and will be completely eliminated in seven years. In addition, the decision to plant is no longer coupled to the subsidy so that rice growers can produce other crops or leave the land idle and still receive the payment. In California, this has meant lower income but not lower acreage since the decision to plant rice is also based on competing crops and land capability. Costs of rice production in California are rising, irrespective of straw management. As an example, using unpublished data from Smith, et.al. (1997) provided by two panels of rice farmers representing moderate (424 acres rice) and large (1365 ac rice) size farms, profitability of rice for the 1996/97 marketing year (1996 crop) can be estimated.

Total production costs, $/ac... $800.00
Total income:
Crop: 75 cwt/ac x $8.00/cwt...... $600.00

Subsidy:[a]......................................	162.20
Subtotal..	$762.20
Net profit (loss)..................................	$(37.80)

[a] Assumes average payment yield of 69 cwt/ac x .85 x $2.7655/cwt. and all acres covered. In reality, many farms receive somewhat less than this because their farmed acreage exceeds the maximum payment so that some acres are not covered by the subsidy.

These figures, which include straw management costs but no living expense, suggest there was little or no profit in rice farming for the 1996 crop. The main causes are low yields, low prices and higher costs. As presented above, cost is increased by straw management. The role of straw in low yields in 1995 and 1996 has not been established; however, the upward trend in diseases supports the conclusion that some yield reduction is likely in fields with medium to high levels of disease.

Smith, et. al. (1997) points out that nationwide rice farms are more dependent on government subsidies than other crop commodity groups, and California is more dependent than most, receiving over 18% of receipts from government payments. The greater impact of the changes in the farm program will be felt in 2003 when direct payments to rice growers are completely eliminated. The extent to which loss of the subsidy will ultimately impact California rice farm profitability is arguable. The rice price assumptions used in Smith, et.al., (1997) are from the Congressional Budget Office, and are national in perspective. They may not accurately reflect the price potential unique to California grown rice. In a 1996 report, Sumner and Lee identified several current and emerging factors that underlie strong economic prospects for the California rice industry. Among them are strong import demand for California rice from Northeast Asia, less competing rice in the US South, and strong domestic demand at higher prices. They project prices will rise to compensate for loss of government income. Which of these scenarios will prevail in the long run remains to be seen. The development of uses for rice straw may generate additional income for growers in the long run, but currently there is little income from sale of rice straw.

In the short run, two consecutive years of low yields (1995 and 1996), the occurrence of a new disease, and other serious production issues that affect overall profitability have created a feeling of crisis in the California rice industry. Growers are reacting to this financial situation by diversifying into other crops, taking cost reduction actions in their rice farming practices, and attempting to renegotiate land rental rates. Complete reliance on a single system of straw management, soil incorporation, is widely considered to be untenable, and felt most keenly by those who are currently farming at a loss. These growers desperately need relief in the form of off-field uses to reduce the annual burden of infield straw management.

Current Cultural Practices and the Amount of Soil Incorporation

Information on acreages burned, incorporated or utilized was developed from several sources, including rough estimates where no reliable record is available. Data is presented in the following table which suggests that 1) growers are complying with the phase down, 2) most favor winter flooding over non-flooded incorporation, and 3) little straw is being utilized.

RICE STRAW PLANTED, BURNED AND UNBURNED

	1994-95		1995-96		1996-97	
	Acres	*Percent*	*Acres*	*Percent*	*Acres*	*Percent*
Planted[a]	514,045	100	500,705	100	514,720	100
Burned[a]	293,210	57	268,216	54	211,322	41
Unburned	220,835	43	232,489	46	303,398	59
Flooded[b]	123,000	24	150,000	30	175,000	34
Unflooded	97,154	19	81,808	16	125,465	24
Utilization[c]	2,043	0.1	2043	0.1	2,933	0.6

a. California Air Resources Board
b Source: 1994/95, C. Ferchaud, DWR; 1995/96 and 1996/97, estimated from various sources
c Source: 1994/95, Report of the Advisory Committee on Alternatives to Rice Straw Burning; other years estimated from various sources.

Potential of Incorporation in Diverting Rice Straw

Though soil incorporation of rice straw is feasible, several potentially damaging impacts of rice straw management are identifiable. Most are not additive over time. However, in each year, isolated damage will likely occur from nutrient deficiencies, toxicities, and stand reduction. Compensating management such as nitrogen fertilizer programs or rotation will have to be used and additional costs will be incurred by the growers. The most likely consequence of continued straw incorporation is an increase of stem diseases if no compensating management is used, and this will likely lead to reduced yield of some magnitude. The long-term effects of winter flooding remain unknown.

In addition to uncertainty concerning productivity impacts of incorporation, weather patterns may impede straw work and create a snowball effect that changes timeliness and effectiveness of operations. Growers simply may not have time to do the work, leading to spring incorporation with the likelihood of greater effects on the crop. We can anticipate that, with such a large scale change in cultural practices, some of the impacts will also be large. We can also anticipate that the results will be a mixture of positive and negative impacts.

Winter flooding is the preferred straw management method because it (1) decomposes straw better, (2) provides waterfowl habitat which may generate income, and (3) fosters a better public image of the rice industry as environmental stewards. However, the system is not equally available for reasons of water supply and costs. The maximum amount of acreage that may be winter flooded when the phase-down reaches full implementation is also an important issue. There are several constraints on water use for winter flooding, particularly as they relate to competing beneficial uses for the same water. In drier years, less water will be available for winter flooding because of the need for irrigation, fish habitat, summer waterfowl programs, and salinity management in the Delta. In dry years, some growers will supplement their available surface water supply with groundwater, to the extent that they can afford to use this more expensive source. In general, however, in drought years, less land will be winter flooded for rice straw decomposition.

As the phase down continues, rice growers will need to have several soil incorporation methods to give them flexibility under various weather conditions. Fall irrigation (versus flooding), may provide another alternative that warrants exploring.

Full implementation of the phase down program, without alternative out-of-field methods of straw disposal, will require all straw be disposed of on farm. It is very doubtful this task can be achieved annually without some disruption of the California rice industry. The magnitude of this disruption will vary depending on many factors.

Recommendations Concerning Cultural Practices

1. *Promote and facilitate research in crop rotation systems, including new crops, to provide additional straw disposal pathways.*

2. *Promote and facilitate continued research on methodology and soil/crop impacts of on farm disposal and removal of rice straw.*

3. *Consider amendments to A* **B-1378** *which will allow permit trading under the conditional burn section*

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